Quantum Hylomorphism, Part I:
An Aristotelian Interpretation of Quantum Mechanics

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Abstract:

Defenders of physicalism (e.g., Brian McLaughlin, Jaegwon Kim, David Papineau) often point to the ontological reduction of chemistry to quantum physics as a paradigm for the reduction of the rest of reality (including the biological, psychological, and social) to a microphysical foundation. This argument is based, however, on a misreading of the philosophical significance of the quantum revolution. A *hylomorphic* (from Aristotle's concepts of *hyle*, matter, and *morphe*, form) interpretation of quantum theory, in which parts and wholes stand in a mutually determining relationship, better fits both the empirical facts and the actual practice of scientists.

In Part I, I argue for the plausibility of a neo-Aristotelian, hylomorphic interpretation of the "pure" or standard version of quantum mechanics (with some reference to quantum field theory). In this Part, I also sketch out the metaphysical thesis of ontological escalation, contrasting it with emergence and supervenience. I consider three modern interpretations of quantum mechanics (the many-worlds interpretation, Bohm's theory, and objective collapse theories) in Part II, arguing that hylomorphic versions of Bohm or objective collapse are superior to the

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alternatives, which collapse into a kind of cosmic monism. In Part III, I turn to thermodynamics and the arrow of time, arguing that only hylomorphic version of quantum mechanics generalizes appropriately to an account of quantum statistical mechanics that is able to treat thermodynamic quantities, like temperature, heat, free energy, and entropy, as genuinely real, which in turn provides grounds for the real directionality of time. Finally, in Part IV I argue that quantum chemistry, in particular, the account of stable molecular structures according to the model of decoherence, further supports the hylomorphic model of ontological escalation.

In section 1 of this part, I explain the connection between microphysicalism and the search for a relatively simple foundation to reality, and in section 2 I explain why many of us find microphysicalism incompatible with an adequate account of rational human agency. I then lay out the hylomorphic alternative to microphysicalism in section 3, which I call "ontological escalation." In section 4 I distinguish ontological escalation from another notion commonly employed in metaphysics: *supervenience*. Then, in section 5, I delineate a persuasive and simple argument from classical physics to microphysicalism—the "straight road to microphysicalism"—followed by five "roadblocks" to this argument created by the quantum revolution. Section 6 consists of two specifically hylomorphic interpretations of quantum mechanics, the pluralist model and the travel-minds model. Finally, I conclude with a brief discussion of cosmic monism and the three modern interpretations, forming a bridge to Part II.

1. Microphysicalism

Why do so many philosophers find microphysicalism—the thesis that only the ultimately microscopic facts are fundamental--so attractive? One motivation has been that of maintaining a unified picture of nature and of our scientific knowledge of nature: the *unity of nature* or *unity of science* ideal. This does give us some reason to minimize the number of fundamental forces that we posit and to resist accepting any violations of the fundamental conservation laws. These reasons, in turn, justify at least to some extent a reluctance to embrace interactionist forms of dualism or vitalism.

However, the unity of nature ideal doesn't give us reason to embrace anything as extreme as physicalism, much less microphysicalism. There is no obvious reason why large, composite objects (like living organisms), fully located within the one world of nature, couldn't possess and exercise fundamental causal powers, even in the absence of new fundamental forces or violations of energy conservation.

The real core of the appeal of microphysicalism has to do with a sense that modern science has vindicated a kind of Democritean ontological reductionism.[2] The thought is that we simply don't need to posit any fundamental agency except at the level of the smallest particles or units of matter. We could, in principle, explain everything in terms of the powers and interactions of the micro-particles, in the sense that everything at higher or larger scales is wholly grounded in the goings-on at the microphysical level.

Modern science provides a framework for a kind of bottom-up reductionist narrative: political and social phenomena reduce to individual psychology, individual psychology to biology (including neuroscience), biology to thermodynamics, thermodynamics to chemistry, chemistry to atomic physics, atomic physics to particle physics. As progress in science over the decades and centuries increases the strength in each link of this chain, anti-reductionists seem to be always on "the wrong side of history," forced into an increasingly desparate form of obscurantism.

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[2] Democritus (460-370 B.C.) was an early defender of philosophical materialism. He famously hypothesized that the only real things are "atoms and the void."

Support for this picture comes from one of the ablest defenses of physicalism within analytic philosophy in recent years: that of Brian McLaughlin (1992). In explaining the "fall" of British empiricism, McLaughlin appeals to two facts: the discovery of DNA, and the quantum mechanical explanation of the chemical bond. Of the two, the apparent reduction of chemistry to physics is most important: first, because it is the crucial first step in chain of reduction leading from microphysics to human agency. If ontological reduction fails there, then the whole Democritean picture is destroyed. Second, the discovery of DNA and other progress in understanding organic processes in terms of their chemical constituents is very far from providing evidence that there is no fundamental biological agency. All that we know from biochemistry is that biological activities are constrained by the presence of appropriate chemical constituents, something that is no surprise to emergentists and other non-physicalists.

In any case, I propose in these papers to focus exclusively on the bottom end of the scale: the relationships between chemistry, thermodynamics, and solid-state physics to particle physics. I will argue that McLaughlin (and nearly all contemporary physicalists) have things exactly backwards: the quantum revolution has, in fact, *not* provided the first missing link in the Great Reductionist Chain of Being. To the contrary, the quantum revolution at the very raises questions anc creates serious problems for microphysicalism. More even that that, it provides us with some good reasons for embracing a metaphysical alternative.

I am not going to argue that the quantum revolution gives us reason to revive something like dualism or vitalism, or even a version of British Emergentism. I will argue that we need to go much further back: all the way back to the Aristotelian tradition of hylomorphism. The quantum revolution was, metaphysically speaking, a counter-revolution, undermining the anti-Aristotelian conclusions that had been drawn in the wake of the first scientific revolution (of the 14th through 19th centuries). The revival of the metaphysics of causal powers in analytic philosophy in recent years provides us with the tools we need to re-evaluate the place of hylomorphism within the quantum understanding of the world.[3]

Paul Feyerabend offered a helpful tripartite distinction of philosophies of science: the positivist, the realist, and the structural (Feyerabend 1983). The positivist is the anti-realist, who denies that reality has any structure that is independent of our interests and assumptions, the "realist" believes that there is a single, unified structure of reality, realized at a single scale, and the structuralist takes reality to comprise a plurality of relatively autonomous structures. The realist or reductionist perspective contributed to the rise and development of modern science, but the quantum revolution has seen a return to the pluralism of Aristotle:

> "Einstein and especially Bohr introduced the idea that [scientific] theories may be context-dependent, different theories being valid in different domains. Combining these ideas with abstract mathematics such as various algebras, lattice theory, and logics then led to a powerful revival of the structural approach. Thus the search for a generalized quantum theory is exactly in Aristotle's spirit: we do not take it for granted that the quantum theories we have are the best way of dealing with everything, looking either for new interpretations or suitable approximation methods to solve hairy cases; we

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[3] Consider, for example, Leo Strauss's assessment of the significance of the anti-Aristotelian revolution:

> Natural right in its classic form is connected with a teleological view of the universe. All natural beings have a natural end, a natural destiny, which determines what kind of operation is good for them. In the case of man, reason is required for discerning these operations: reason determines what is by nature right with regard to man's natural end. The teleological view of the universe, of which the teleological view of man forms a part, would seem to have been destroyed by modern natural science. Form the point of view of Aristotle—and who could dare to claim to be a better judge in this matter than Aristotle?—the issue between the mechanical and the teleological conception of the universe is decided by the manner in which the problem of the heavens, the heavenly bodies, and their motion is solved (Physics 196a255, 199a3-5). (Strauss 1950, pp. 7-8)

rather try to identify domains and theories suited for them and then look for ways of relating these theories to each other." (Feyerabend 1983, vii)

2. Microphysicalism and Rational Human Agency

Microphysicalism, the thesis that all facts are wholly grounded in the ultimately microscopic facts of the physical world, has always stood in some tension with our common-sense understanding of ourselves as rational agents. For example, in the *Phaedo*, Plato puts into Socrates' mouth an argument against metaphysical microphysicalism (98c-99b).

P1. I have intentions.

P2. The content of any of my intentions is wholly grounded in what seems best to me to do.

P3. What seems best to me to do is at least partly grounded in the real values of things.

P4. So, there are intentions of mine whose contents are at least partly grounded in the real values of things.[4] (From P1-P3)

[4] I am assuming that it's obvious that my intentions are not *causally* (i.e., extrinsically) connected to the real values of things. If that causal connection were a possibility, then I would have to add a premise to the effect that the microphysical facts (and whatever is wholly grounded in them) are not causally connected to the real values of things--which also seems quite plausible.

P5. The real values of things are not partly (weakly) grounded by the microphysical facts.[5] (*Weak grounding* is the reflexive counterpart to grounding—see Fine 2012.)

P6. If microphysicalism is true, then (by its definition) microphysical facts are not partly (weakly) grounded in the facts about the real values of things, since they are metaphysically fundamental.

P7. No Over-Grounding: If *x* is wholly grounded in the y's and partly grounded in the *z*'s, then either the *y*'s are partly (weakly) grounded in the *z*'s or the *z*'s in the *y*'s.

P8. So, the contents of my intentions are not wholly grounded in the microphysical facts. (From P4-P7)

P9. Therefore, microphysicalism is false.

The first three premises are predicated on the idea (ably defended in recent years by Jonathan Dancy) that our intentions can be sensitive to *reasons*, considered as

[5] I am not denying that the value of *particular* objects, events, and situations are partially grounded in the particular microphysical facts (as reflected in Moore's principle of the supervenience of evaluative facts on natural facts). By "the value of things" I mean the value of *general* properties and property-configurations: the value of health in general, for example, and not the value of the state of someone's body at a time. I am claiming that the facts about which *kind*s of thing favor which *kinds* of action are not grounded in the microphysical facts.

objective facts about what actions are favored in various circumstances. A second version of the argument would involve focusing more narrowly on fully rational intentions and justified seemings:

P1*. I have *rational* intentions.

P2.* The content of any of my rational intentions is wholly grounded in what *reasonably* seems best to me to do.

P3.* What *reasonably* seems best to me to do is at least partly grounded in the real values of things.

Microphysicalists have essentially two options in response to this argument: they can deny the existence of real or objective values altogether, or they can claim that objective values are somehow wholly grounded in the microphysical facts. Neither seems promising. Jonathan Dancy, Christina Korsgaard and many others in recent years have created powerful objections to a Humean subjectivism about value. And, in any case, it seems that subjective values must ultimately be grounded in objective value, if reason is to have any normative force at all. Even if one supposes that particular things are good for an agent only because he or she desires them, one must still suppose that desires are the sort of thing that (other things being equal) ought to be satisfied—that there is something objectively worthy about seeking to satisfy them.

Microphysicalists might attempt to combine the second option with a *tu quoque* argument directed to the Aristotelian hylomorphist. One might suppose that objective values are grounded in whatever the hylomorphist takes them to be grounded in—say, the structure of human nature—and then postulate that this intermediate level of teleologically ordered human nature is itself wholly grounded in the microphysical facts (including evolutionary history and natural selection). This response would miss its mark, since the most plausible Aristotelian account of objective value would take the structure of human nature (as the nature of a rational animal) to be partly grounded in the real values of things, and not vice versa. Aristotelian hylomorphists have traditionally taken the rational nature of human beings to be partially grounded in universal truths (like the real values of things) and only partly grounded in the natures of our microscopic parts. In addition, there are strong objections to the grounding of the teleology of the human mind in microphysical facts, as Alexander Pruss and I have argued (Koons 2010). The best microphysicalist account of the mind is functionalism, but functionalism cannot work unless the whole organism possesses fundamental causal powers (Koons and Pruss 2015).

3. Ontological "Emergence" & Downward Determination: A Hylomorphic Alternative

I am going to defend a version of strong or ontological "emergence," but I prefer not to use that term. There are four drawbacks to the term "emergence" and the associated picture:

1. *An overemphasis on the bottom-up determination*. Many emergentists seek to preserve the unity of nature by keeping the micro in ultimate control. The language of "emergence" suggests a certain priority of the micro: the macro level must "emerge from" the micro level, but there is no parallel requirement that the micro level "submerge" or "diverge" from the macro. This privileging of the bottom level is associated with what I would call the *Myth of the Unique Universality of Particle Physics*. I would argue that political science is just as universal as biology, since it is

just as much a judgment of political science that certain organisms are non-human or non-rational as it is that some are human. Similarly, it is a biological matter to claim that some chemical system is non-living, and it is a chemical matter to assert that certain particles fail to form a molecule. Thus, politics, biology, and chemistry are just as universal as is particle physics. There may be certain principles that are truly universal in a stronger sense, such as the law of the conservation of energy or the constancy of the speed of light, but these principles are no more associated with particle physics or quantum field theory than they are with any other special science.

2. *'Emergence' as become too variegated in meaning*. In the ninety years since talk of 'emergence' was popularized by Samuel Alexander and C. D. Broad, the term has been subjected to a bewildering variety of senses and sub-varietes, including weak and strong and epistemological and ontological emergence. Many (including Jaegwon Kim) have tied the notion of *emergence* with ideas of supervenience, which is largely a red herring. It's time to consider making a new start with fresh vocabulary.

3. *New fundamental forces*. In its strong form (Broad 1925), emergentism includes the postulating of new fundamental forces—"configurational" forces. In this respect, it comes very close to vitalism or dualism. I will argue that the causal autonomy of complex entities does not require forces beyond the three or four currently accepted by the sciences (gravity, the electroweak force, and the strong nuclear force).

4. *Defined in contrast to "theory reduction, " understood as a logical or deductive relation.* However, theoretical reduction is compatible with ontological and causal novelty at larger scales of composition, as I will argue below.

Consequently, I will make use of the neologism 'ontological escalation'. One advantage of this phrase is the etymological connection between 'escalate' and ‘scale’: according to the thesis of ontological escalation, properties and powers “emerge” at one of a number of different levels of scale, with different levels on an ontological par. No priority is given to the very small.

Thesis of Ontological Escalation

1. The world consists of a number of levels of compositional scale, with each scale-level consisting of a domain that includes certain fundamental entities with certain fundamental properties and mutual relations.

2. Except for the very smallest scale, the entities of each scale-level are composed entirely of smaller-scale entities, and the powers of and causally relevant relations among those entities are partly *grounded in* facts about the smaller-scale entities. (That is, the larger-scale entities have the causal powers they do in part *in virtue of* their smaller-scale parts and their properties.)

3. Except for the very largest scale, the powers of and causally relevant relations among entities of each scale-level are partly grounded in facts about larger-scale entities.

Thus, larger-scale entities *both* condition and are conditioned by smaller-scale entities, in relations of mutual metaphysical co-determination.

The thesis of ontological escalation does not require vicious circles of metaphysical grounding. The entities at each level of the scale have some ungrounded properties, and the causal powers of and relevant relations among those entities are grounded partly in those autonomous properties, partly in the ungrounded properties and relations of the entity’s parts, and partly in the ungrounded properties of the wholes at larger scales in which the entity is incorporated. The main idea is that there is a rough equality among the various scale-levels, with the entities of two successive levels constraining one another in different ways.[6]

I will defend in particular a neo-Aristotelian orhylomorphic conception of ontological escalation, in which top-down determination corresponds to Aristotle's notion of formal causation, and bottom-determination corresponds to material causation, building on my recent paper, "Staunch vs. Fainthearted Hylomorphism" (Koons 2014).

Let's say that a set A of possible entities *is compositionally higher than* a set B of possible entities just in case B includes some (proper) parts[7] of every member of A, and A includes no proper parts of any members of B. A set of properties and relations P *is compositionally higher than* a set of properties and relations Q just in case the set of possible bearers of P is compositionally higher than the set of possible bearers of Q. A *domain* D is a maximal set of properties and relations of

[6] As we shall see, the threat of circularity can be avoided in a number of ways. For example, it could be (as I argued in Koons 2014) that composite things are diachronically *dependent on* the arrangement of their parts in the past but synchronically *prior to* the precise locations and the intrinsic properties of those same parts in the present. Alternatively, it could be that wholes are dependent on the *existence* of parts of certain kinds and their location in a certain *region* of space, but that the *precise* locations and spatial interrelations of those parts are dependent on the nature of the whole. Thirdly, if materials things can evolve indeterministically, these stochastic powers can be borne most fundamentally by wholes rather than their constituent parts.

[7] Contemporary metaphysicians tend to talk of 'proper parts', because it is convenient to define 'part' in such a way as to include the case of a thing's being an "improper part" of itself. A *proper part* of x is a part of x that is not identical to x itself—essentially, what 'part' means in ordinary English.

such a kind that no subset of D is compositionally higher than any other subset of D. A domain D_1 is *of larger scale than* domain D_2 just in case some subset of D_1 is compositionally higher than some subset of D_2. The larger-scale relation is provably irreflexive and transitive (a partial ordering). I conjecture that it is, as a matter of scientific fact, a linear ordering.

My picture is close to the model of emergence by fusion proposed by Paul Humphreys (1997). In Humphreys's model, the entities of the smaller-sclale levels are literally destroyed in a diachronic process of fusion (the generation of the new, larger-scale entity). This kind of destructive fusion could count as an extreme case of ontological escalation, so long as we consider the "annihilated" *summands* as enjoying some kind of virtual or dependent existence within the fused entity. Even if we suppose that the lower-level entites do not survive the process, we might still count Humphreys's model as a form of ontological escalation, since the small-scale internal development of the the larger-scale entities would be simultaneously or constitutively grounded in the nature of those larger-scale entities, and the larger-scale entities would dependent over time on the dynamical properties of the small-scale *summands* that can enter into the fusion process.

As I argued in Koons 2014, I defend a broader account of escalation, one encompassing Humphreys's model as a special case. (In fact, I will argue in Part III that, in the case of phase transitions in condensed-matter physics, we have good grounds for endorsing something very much like Humphreys's fusion model.) Even when the summands survive as components of a larger-scale entity, we can have a case of ontological escalation, so long as the dynamic interactions between the smaller-scale entities are grounded in the nature of the larger-scale fusion. This can happen, without the introduction of any new fundamental forces (including configurational forces) so long as the spatiality and spatial inter-relatedness of the smaller-scale entities depends in part on their participation in a larger-scale whole, or so long as the intrinsic causal powers of the parts are absorbed by and grounded in the powers of composite whole.

Ontological escalation differs somewhat from the model of ontological emergence proposed by Timothy O'Connor and his collaborators (O'Connor 1994, O'Connor and Wong 2005), who, like Humphreys, postulate a diachronic process of generation of the emergent entities. In O'Connor-style emergence, the constituents do survive the fusion. However, O'Connor supposes that there is some kind of non-supervenient downward causation, involving new configurational forces (as in Broad's account). This comes close to a kind of vitalism or dualism (as I argued in Koons 2014), and its plausibility is weakened by our natural reluctance to posit new fundamental forces. In addition, O'Connor assumes a kind of original or primordial *universality* of the micro-level, which must contain in a virtual way all the higher levels. With ontological escalation, in contrast, all of the levels are equally universal and primordial (at least potentially).

Bernard Williams famously accused hylomorphism of being merely a "polite form of materialism." Is ontological escalation equally vulnerable to the charge of being merely a polite form of microphysicalism? I would argue that it is not, on the grounds that microphysicalism must be committed to the *one-way dependence* of all larger-scale levels on the one, ultimately microscopic level of fundamental entities. As long as we insist on an *equal* dependence of the small on the large, we can avoid microphysicalism. We also avoid, at the same time, the equally imperialistic extreme of cosmic monism, according to which only the whole universe is fundamental (as defended recently by Jonathan Schaffer 2010). As often happens, the two extremes of atomism and cosmic monism have much in common, in sharp contrast to the pluralism of ontological escalation or multi-scale realism.

4. Supervenience vs. Escalation

In the 70's, 80's and 90's of the last century, many analytic philosophers hoped that the notion of the supervenience of mental properties on physical properties and of higher-level properties of composite things on the properties of their component parts would settle the debate over microphysicalism, in favor of a "non-reductive" form of microphysicalism, in which non-physical facts and facts about composite entities were "nothing over and above" the microphysical facts, even if they were not deducible by us (given our conceptual and epistemic limitations) from the corresponding microphysical truths.

The notion of 'supervenience' (although not the term) was introduced into modern philosophy by G. E. Moore in the early twentieth century, who made a quite compelling case for the claim that all moral and aesthetic facts supervene on the domain of natural facts, in the sense that it would be impossible for a moral or aesthetic to be different from what it is without there being some relevant change in the natural facts. We cannot imagine a beautiful painting's being (in some alternatives scenario) ugly, if we suppose that it would still have all the same physical and chemical characteristics (that is, no change in the arrangement or composition of its pigments and canvas). In mid-century, Oxford philosopher R. M. Hare introduced a new technical sense of the word 'supervene' to capture this relation. Later, American philosopher Donald Davidson used supervenience as a means of expressing a new kind of physicalism, according to which mental events supervene on the physical events.

Supervenience is a *modal* relation among facts (or properties): a relation that corresponds to which combinations of properties are possible and which impossible. Both microphysicalism and ontological esclation, in contrast, are *metaphysical* relations among domains of entities, natural properties, and causal powers. There is no simple definition of either microphysicalism or ontological escalation in terms of supervenience or its absence. Let me review briefly why this must be so.

Take a look at supervenience. Here is the simplest definition of the (local, weak) supervenience of the A-properties on the B-properties:

Entities *x* and *y* are *A*- (*B*-) *duplicates* just in case they do not differ with respect to their *A*- (*B*-) properties.

Supervenience of A-properties on B-properties:
Necessarily, if two things are *B*-duplicates, then they are also *A*-duplicates.

In the late twentieth century, many philosophers hoped that supervenience could be used as a criterion for metaphysical dependency: the *A*-properties depend on the *B*-properties if and only if they supervene on them. There is, however, a crucial difficulty with this proposal: supervenience, unlike dependency, is not asymmetric. Consequently, supervenience cannot entail dependency.

Microphysicalists subtly assume that there is no grounding of the microphysical in the macro-levels: no real explanation of the microphysical in terms of the macro-levels. That is, they assume that the micro-level is ungrounded, independent, and fundamental. Given this assumption and the supervenience of everything on the microphysical, the non-fundamental character of the macro-levels does follow—if we make the plausible assumption that it is impossible for one class of ungrounded properties to supervene on another. If class *A* supervenes on class *B*, there must be some explanation of this fact in terms of metaphysical dependency, although this explanation need not take the form of the dependency of *A* on *B*. Thus, dependency or grounding cannot be defined in terms of supervenience, but supervenience is a phenomenon that *demands explanation* in terms of grounding.[8] We can call this rule

[8] Grounding can supply the needed explanation, given two plausible assumptions: (i) if the fact that *p* grounds the fact that *q*, then the truth of *p* necessitates that of *q*,

the Reichenbach principle for grounding (an analogue of a comparable rule proposed by Hans Reichenbach with respect to causation):

The Reichenbach rule for grounding: whenever there is a metaphysically necessary connection between two disjoint sets of properties (such as supervenience) there is an explanation for this connection in terms of grounding: either the instantiation of one set is wholly grounded in the instantiation of the other set, or both sets are grounded in some third set.

Corollary to the Reichenbach principle: If set *A* supervenes on set *B*, and the facts about the instantiation of the *B*-properties are fundamental (ungrounded), then the *A*-facts are wholly grounded in the *B*-facts.

Microphysicalism depends on a Democritean starting point, namely, that facts about atoms and the void are *ungrounded* facts. This ungrounded foundation consists of microscopic entities with certain intrinsic characteristics (*shape* and *size* for Democritus, but this can be extended to include things like *charge*, *mass*, *spin*, and so on), and certain instantaneous spatial relations. All spatial relations can be ultimately grounded in a large number of simple binary or ternary relations among the microscopic entities (distance certainly, perhaps also angles between inter-atom directions). Atoms and the void constitute the fundamental level, and everything else supervenes on them.

Aristotle's hylomorphic model denied the ungroundedness of the microscopic realm. The intrinsic characters of and mutual relations (including spatial relations) among the microscopic entities are typically (or at least often) grounded in the natures of the macroscopic entities of which they are parts. Consequently, for Aristotelians, the

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and (ii) if the fact that *p* grounds the fact that *q*, then the fact that *q* is necessarily grounded by some fact like the fact that *p*.

supervenience of the macro-world on the micro-world would not indicate the metaphysical dependency of the first on the second.

Although macro-on-micro supervenience is irrelevant to the Democritus/Aristotle controversy, the same is not true for the *absence* of such supervenience. If macrophysical properties do *not* supervene on microphysical properties, this decisively refutes the Democritean picture. The quantum revolution supports Aristotle in both ways: by questioning the ungrounded character of the micro-level, and by providing some good reason for denying the supervenience of the macro-level on the micro-.

4.2 How then can we Detect Ontological Escalation?

The epistemological task is complicated by the fact that ontological escalation entails neither the absence of supervenience nor the failure of reduction. However, the situation isn't desperate, we simply have to exercise a certain amount of creativity and look carefully at the details of our best scientific and metaphysical theories.

First, we can look for evidence that large-scale domains play an indispensable role in tying together small-scale entities and in connecting them to our familiar three-dimensional space. In fact, as we shall see, the quantum picture of extremely small objects leaves them with a tenuous and indeterminate relationship to the three-dimensional space of ordinary human and classical physical experience. A variety of macroscopic chemical and physical actions (colliding, striking, breaking, rolling, gluing, fastening, and so on) depend upon objects' having determinate locations in space, as does the action of each of the fundamental forces (gravity, etc.).

Second, we can look for indirect evidence (e.g., from Bose-Einstein statistics) of small-scale objects losing their individuality and distinctness when fused or aggregated.

Third, we can look for evidence that the spatial discreteness and separation of small-scale entities vanishes in certain dynamic contexts. This would strongly suggest that, even if they continue to exist within some large-scale aggregate, the way in which the small-scale entities occupy space and thus interact with one another and with their environment is significantly different, thanks to the top-down influence of the aggregates' natures. (This is a possibility that I will take up in Part III, in connection with thermodynamic properties.)

Fourth, failures of macro-on-micro supervenience can flag the existence of fundamental macroscopic facts.

5. The Straight Road to Microphysicalism

In classical Newton-Maxwell-Special-Relativity (NMSR) paradigm, it was hard to see how the fundamental particles and their locations in space could fail to be fundamental, and how the macroscopic could fail to supervene on that fundamental level. All that changes with the quantum revolution, but philosophers have not yet absorbed the crucial lessons.

5.1 The Straight Road Argument

Let me try to formulate carefully the argument that follows what I am calling the "Straight Road" from the NMSR paradigm to metaphysical microphysicalism or Democritianism.

SR1. The facts about the instantaneous intrinsic states, binary spatial relations, and velocities of the ultimately microscopic entities of the world (the "microphysical facts") are metaphysically fundamental (ungrounded).

SR2. All the other facts of the world supervene on the microphysical facts.

SR3. The Corollary of Reichenbach's principle: whatever supervenes on some metaphysically fundamental facts is wholly grounded in those facts.

SR4. Therefore, all other facts are wholly grounded in the microphysical facts.

5.2 The First Quantum Roadblock: The Copenhagen Version of Quantum Mechanics

Let's turn again to the first two premises of the Straight Road argument:

SR1. The facts about the instantaneous intrinsic states, binary spatial relations, and velocities of the ultimately microscopic entities of the world (the "microphysical facts") are metaphysically fundamental (ungrounded).

SR2. All the other facts of the world supervene on the microphysical facts.

The standard or so-called "Copenhagen" interpretation gives us reason to doubt both of these premises. In the Copenhagen interpretation, the microphysical facts consist in the attribution to microscopic entities of certain potentialities, and these potentialities essentially include causal relations to macroscopic systems. A quantum doesn't typically have any position or momentum at all (not even a vague or fuzzy one): it has merely the potential to interact with macroscopic systems as if it had some definite position or momentum (or other observable feature) at the moment of the interaction. Thus, the quantum world (so understood) can be neither metaphysically fundamental (contra SR1) nor a complete supervenience basis for the macroscopic world (contra SR2).

Of course, this situation gives rise immediately to a puzzle: what, then, is the relationship between the macroscopic and quantum worlds? Presumably, macroscopic physical objects are wholly composed of quanta. How, then, can the quanta fail to be metaphysically fundamental and a supervenience basis for the macroscopic world?

Hylomorphic ontological escalation offers a ready answer to this puzzle. The microscopic constituents of macroscopic objects have (at the level of actuality) only an indirect relation to space and time: they are located (roughly) somewhere at a time only *qua* constituents of some fundamental, macro- or mesoscopic substance (in the Aristotelian sense). Such microscopic objects are not metaphysically fundamental in their entirety, and their metaphysically fundamental features do not provide a supervenience basis for the features of the substantial wholes they compose. This is a welcome result, since it makes physical theory compatible with the conclusion of the *Phaedo* argument.

Nonetheless, we would still like to know more about how, in detail, the facts about the microscopic parts and their macroscopic wholes constrain and determine each other. I will turn to this question in section 5.

5.3 The Second Quantum Roadblock: Non-separability of Quantum States

The most obvious blow that quantum mechanics strikes to microphysicalism comes from the undeniable 'non-separability' of the quantum properties of entangled systems. As noted by Teller (1986), Healey (1991), Silberstein and McGeever (1999, pp. 186-90), Kronz and Tiehen (2002, pp. 325-330), along with many others, the quantum state of a pair of entangled particles is irreducibly a state of the pair as such: it does not even supervene on the intrinsic properties or spatial distance between the particles. In these cases, the whole is literally more than the sum of its parts.

For a long time, philosophers assumed that this sort of quantum weirdness could be limited somehow to the microscopic domain, being almost completely swamped at the phenomenlogical level by phenomena that completely conform to the requirements of microphysicalism. However, it turns out that this kind of quantum holism is very much the rule rather than the exception, producing measurable results at the phenomological level nearly all the time (Primas 1980, p. 41).

In addition, the holistic character of the fundamental states becomes even clearer when we move from original quantum mechanics to quantum field theory. In quantum field theory, it is impossible to assign any value whatsoever to dimensionless spacetime points: instead, the expected field values must be defined ("smeared out") over voluminous spacetime regions (see Baker 2009. p. 591; Lupher 2010). Consequently, it is extended regions and not the ultimately microscopic points that are the fundamental property-bearers.

One might object that this doesn't bring out any tension between QFT and microphysicalism, since it is consistent with the smearing-out requirement that all facts about macroscopic regions are wholly grounded in facts about microscopic regions (just not on microscopic points). However, at this point the microphysicalist faces a dilemma: either there is an infinite regress of grounding relations (with the field-property of each region wholly grounded in the properties of its sub-regions), or spacetime is discrete, rather than gunky, with spatiotemporally minimum regions (indivisible but extended spacetime atoms). Both horns of the dilemma are costly.

First, if spacetime and extended fields are truly "gunky,"[9] and the quantitative facts about those fields form infinite grounding-regresses, then none of those facts are metaphysically fundamental. On this horn of the dilemma, all the facts about field-regions are equally non-fundamental, including all of the facts about the grounding relation itself. First, this lack of fundamentality is itself objectionable: there is something at least troubling about an infinite regress of dependency relations. Second, such a theory lacks ontological parsimony, because we cannot pick out a relatively sparse subset of fundamental facts to bear the burden of justifying the positing of the other facts. It undermines the principle ontological advantage of microphysicalism: the fact that we can treat certain microphysical facts as fundamental and as grounds for all other facts. Finally, we should look for some metaphysical explanation of each of the infinite grounding regresses, which would lead us to posit some *ultimate* grounds for all of the ungrounded facts. These ultimate grounds would have to consist either of facts about extended spacetime regions or facts that are entirely non-spatiotemporal. The first case is inconsistent with microphysicalism (given the transitivity and irreflexivity of the grounding relation), since the properties of the sub-regions of the fundamental regions must be grounded in the properties of the whole region, contrary to the bottom-up grounding requirement of microphysicalism. In addition, in that case we would have good reason to take relatively large regions regions as the source of the ultimate grounding (regions that partition spacetime into mutually exclusive and jointly exhaustive cells), on the grounds of parsimony: there are many fewer such regions than there are microscopic ones.

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[9] 'Gunk' was a term introduced by David K. Lewis to refer to the hypothetical possibility of material stuff that is infinitely divisible but contains no indivisible parts whatsoever. In this case, we're primarily interested in what might be called "spatial gunk": an extended substance that fills a region of space, has parts that fill each of its subregions, but no parts that occupy precisely point-sized (and indivisible) locations.

Why couldn't the microphysicalist then adopt a theory of discrete, non-gunky spacetime: a "gritty" spacetime with minimum extended parts? This is certainly possible, but it does come at some cost. First of all, there are well-known paradoxes concerning motion through such a "gritty" spacetime, paradoxes discovered by Zeno and discussed by Aristotle. Second, such a theory faces seriously challenges in meeting the condition of Lorentz-invariance required by special relativity. Presumably, the minimum atoms of spacetime should have some uniform size and shape (something in the neighborhood of the Planck length), but in special relativity there is no such thing as absolute size or shape.

5.4 The Third Quantum Roadblock: The Fusion of Microscopic Individuals

Quantum mechanics, unlike classical statistical mechanics, treats indiscernible particles as if they had lost all individuality, having been absorbed into an undivided unity with an internal structure that registers only the bare number of particles of each type. It no longer makes any sense to ask which particular particles instantiate which type. This fusion of individuals shows up most vividly in the Bose-Einstein statistics of quantum theory. For instance, if we have a two-particle system and two possible spins ("up" and "down") for each particle, classical statistics recognizes four possible states (both up, both down, one particle up and the other down, and a fourth state, similar to the first but with the two particles' switching their respective roles). Bose-Einstein statistics, the basis of quantum probabilities, recognizes only three states. The third and fourth classical states are no longer distinct, since there are no longer two distinct particles in the quantum fusion.

This quantum fusion phenomenon is the basis of Paul Humphreys's 1997 model of emergence.

Kronz and Tiehen (2002) also appeal to the nonseparable evolution of quantum systems as grounds for doubting the continued, distinct existence of the "components":

> [T]he simplicity of the algorithm and the complexity of solving the resulting equations are primarily epistemic considerations, and focusing on them directs attention away from the crucial ontological features of quantum models that have nonseparable Hamiltonians. Ultimately, it is not the simplicity or complexity of the algorithm that is crucial. What is crucial is what the resulting structure shows about the relationships existing between the causal features of the components. More to the point, the causal features remain independent in their action in the classical case involving forces. By contrast, the causal features in the quantum models discussed above become inextricably linked due to a continual essential interaction. It may be that such links are so robust that it is no longer meaningful to talk about components that are [occurrent] parts of a compound, meaning that there are "components" only with reference to what existed prior to the interaction and what exists after the interaction has ceased. (Kronz and Tiehen 2002, p. 340)

However, the hylomorphist should not claim that human beings or other organisms or macroscopic entities are simply complex quantum-mechanical systems, governed by some n-particle Schrödinger equation for some very large n. It is unlikely that every particle in my body is entangled in this way with every other particle in my body, and it is almost certain that some particles in my body are entangled that are scattered far and wide in the environment. Nonetheless, the existence of ontological fusion at the quantum level significantly raises the plausibility of supposing there to be other cases of objective holism in still larger-scale, non-quantum domains (like biology and political science).

5.5 The Fourth Quantum Roadblock: The Non-Fundamentality of Particles and Fields

In this subsection, I will make a very brief digression into Quantum Field Theory, which most physicists and philosophers hold to be more fundamental than the original quantum mechanics of the early and mid twentieth centuries, and which is consistent with special relativity.

If microphysicalism is true, then there must be some fundamental microphysical entities, that is, entities that are located in very small regions of spacetime (ideally, at dimensionless points). There are only two viable candidates to play this role: fundamental particles, or fundamental fields. A particle is a bit of matter that occupies at each moment some minimal region of space, such as a point. A field fills all of space (or some very large region), with a definite quantity of some kind (scalar, vector, or tensor) at every point in space at each moment.

Recent work in the philosophy of physics has built a strong case for the claim that quantum field theory is inconsistent with the existence of fundamental particles (Malament 1996, Clifton and Halvorson 2002, and Fraser 2008). Here we can point to a number of facts, including the fact that the quantum vacuum has real causal power, despite the complete absence there of particles (Wald 1994). In addition, the very number of particles that are contained in a given system can vary, depending upon one's frame of references (accelerated vs. inertial), the so-called "Rindler quanta" or "Unruh effect" phemomenon (Clifton and Halvorson 2001). Fundamental entities cannot have a merely frame-relative existence. Finally, Fraser (2008) points out that our best theories of interacting fields leave no room for fundamental particles.

More recently, David John Baker (2009) has argued that quantum field theory is equally incompatible with the existence of fundamental *fields*. His central arguments turn on the phenomena of frame-relativity of field quantities (the Rindler quanta problem again) and of *spontaneous symmetry breaking*. In quantum field theory, which properties (that is, which *determinable* properties) a field has at each spacetime point can depend on contingent facts about how certain symmetries have been "broken" in the course of cosmic history. On the plausible assumption that it is a matter of metaphysical (or at least physical) necessity which properties are metaphysically fundamental, it follows that there are no fundamental wave properties in QFT. Baker points out the inconsistency of the following four propositions (Baker 2009, pp. 597-8):

(F1) The smeared fields are the fundamental physical quantities according to the wavefunctional interpretation.

(F2) The outcome of spontaneous symmetry breaking (SSB) determines which quantities are the fields.

(F3) The outcome of SSB is physically contingent, since it depends on initial conditions.

(F4) Which quantities are fundamental is a physically necessary fact.

Since we have good reason to accept (F2)-(F4), we should reject (F1). The field-strength properties of spacetime regions are no more fundamental (according to QFT) than are the properties of spatially localizable particles.

What then can be fundamental, according to QFT? If we set aside the Copenhagen interpretation (according to which no quantum-mechanical facts are fundamental at all), QFT forces us to attribute the status of metaphysically fundamental status to states that are entirely "outside" our familiar 3+1-dimensional spacetime. This is the position of wavefunction realism, which is embraced by the three new interpretations of quantum mechanics that we will consider in section 7.

5.6 The Fifth Quantum Roadblock: The Fundamentality of Total Energy and Action

The Straight Road argument can be challenged in yet another way. In this case, I will argue against premise SR2, the (metaphysical) supervenience of the macrophysical facts on the microphysical. Even if the macrophysical facts do follow logically from a set of microphysical facts and purely microphysical dynamical laws, it does not follow that all of the macrophysical facts supervene metaphysically on the microphysical ones, since we still have to take into account which properties participate in the (metaphysically*) fundamental* dynamic laws. It may be that the purely microphysical dynamical laws are themselves grounded in certain partly macrophysical laws. For example, it might be that the Newtonian laws of motion are grounded in certain laws concerning total energy or total action of complex systems.

This possibility was already present implicitly in classical mechanics, as Leibniz already understood. Classical mechanics can be formulated in either of two ways: in terms of differential equations based on Newton's laws of motion, or in terms of integral equations in terms of the conservation of energy (the analytic or Hamiltonian method). In the latter case, the phase space consists in certain constraints on the evolution of the system, and the dynamical laws pick out the actual evolution on the basis of some minimization (or maximization) principle, like the principle of *least action*. (See Yourgrau and Mandelstam 1979, pp. 19-23, 164-167; Lindsay and Morgenaw 1957, pp. 133-6; Lacszlo 1986, pp. xxvii, 345-6.) The Newtonian model is Democritean, but the Hamiltonian is Aristotelian, both essentially holistic and teleological. The total energy of a closed system is an irreducibly holistic or non-separable property of the system: it cannot be reduced to the intrinsic properties of the system's constituents, taken individually. More importantly, variational principles like the least action principle treat the holistic character of an entire trajectory as fundamental, rather than the set of instantaneous facts about the composition of forces that constitutes the fundamental facts for the Newtonian model. The least-action principle is a form of teleological explanation, as Leibniz already recognized (McDonough 2008, 2009).

In classical mechanics, either model can be used, and they are provably equivalent. Hence, classical mechanics leaves the metaphysical question of microphysicalism vs. ontological escalation unresolved. However, with the quantum revolution, the Hamiltonian picture becomes mandatory, since the fundamental entities can no longer be imagined to be moving in response to the composition of forces exerted at each moment from determinate distances. Teleology reigns supreme over mechanical forces, as Max Planck noted. (See Planck 1936, pp. 119-126; Planck 1960; Dusek 2001; Thalos 2013, pp. 84-86.) In addition, *the total energy and action of a closed system are essentially holistic or non-separable properties of that composite system*, which stands in contradiction to the demands of microphysicalism.

In addition, by forcing reliance on the Hamiltonian model, quantum mechanics brings into sharper relief the holistic character of causal interaction. As noted by Tiehen and Kronz (2002), the Hamiltonian for complex quantum systems is non-separable: "In that case, the time evolution of the density operator that is associated with a part of a composite system cannot in general be characterized in a way that is independent of the tie evolution of the whole." (Kronz and Tiehen 2002, pp. 343-4) The causal power responsible for the evolution of the system is an irreducibly joint power, not supervening on the binary causal powers of the component particles.

Aristotelian philosophy of nature requires processes as the natural results of the exercise of causal powers. These Aristotelian processes (kineses) have intrinsic direction and pacing.[10] Aristotle did not, as his late medieval and early modern critics supposed, anthromorphize nature by attributing vague 'urges' or 'drives'; rather, he developed a framework within which animal and human drives could be seen as special cases of the intrinsic directedness of holistic processes. The system as a whole consequently acquires its own intrinsic teleology (or, better, *entelechy*).

We might summarize this point by distinguishing three grades of teleology:

(a) The lowest grade requires only fundamental causal powers. Both active and passive powers have an intrinsic orientation toward the future, which George Molnar correctly identified as a kind of *natural intentionality*.

(b) For the second grade of teleology, we need fundamental causal powers at the level of pluralities and composite entities, not just the simples. Energy (as a fundamental factor) already gives us that: total energy is an essentially holistic property of a closed system. If teleology begins and ends with the microscopic mereological simples (as John Heil, for example, advocates), then there's no room for biological or mental teleology.

(c) The highest grade of teleology requires a unified, fundamental quality that attaches to whole, temporally extended *processes*, and not just to instantaneous

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[10] Schulman (1989) draws out a fascinating parallel between Aristotle's account of motion as 'potential' and 'indeterminate' in *Physics* III and *Metaphysics* III and Richard Feynman's sum over possible histories approach to quantum mechanics. Aristotle denies that the location of a moving body is fully *actual* except at the beginning and end of a continuous process of locomotion. Feynman's sum-over-histories approach is a way of fleshing this out: the moving body takes every possible trajectory between the two points, with mutual interference explaining why the paths with least action predominate.

events or actions. This fundamental quality, in turn, must be the feature that is responsible for the actual occurrence of processes that have it, in contrast to competing processes that do not.

For example, in Aristotle's biology the end of an organism is a certain kind of *living*, a form of activity. Likewise, in his astronomy the final cause of each of the heavenly spheres is a certain kind of eternal, circular motion. Teleology does not require a fixed, concluding *state* to which a thing is moving. That sort of end-state teleology is derivative to the more fundamental, quality-of-ongoing-activity sort of teology. In fact, it's hard to find examples of static-end teleology in Aristotle's corpus: even processes like healing, growth, learning, and development culminate in *processes*—the lively activities of the mature adult.

The variational principles of quantum mechanics reach the highest grade of teleology.

6 Two Versions of Quantum Hylomorphism

There are at least two ways in which hylomorphic escalation and quantum theory can be combined. These two versions differ on a single issue: do the quanta of the world form a single system, whose dynamical evolution is consistent and uniform throughout time? The first version, Alex Pruss's Traveling Forms Interpretation, answers Yes. The second version, Pluralistic Quantum Hylomorphism (PQHM) or the "dappled world" model, answers No. Let me describe the two versions in reverse order.

6.1 Pluralistic Hylomorphism, or the Dappled World

Pluralistic Quantum Hylomorphism is an interpretation inspired by some remarks of Heisenberg (1958), and defended by Wolfgang Smith (2005), Nancy Cartwright

(1999) and Stanley Grove (2008).[11] On this view, the world consists of a variety of domains, each at a different level of scale. Most of these domains are fully classical, consisting of entities with mutually compatible or commutative properties. At most one domain is accurately described by quantum mechanics. Since location does not (for quantum objects) "commute" with other observables, like momentum, the quantum objects are only intermittently located in ordinary, three-dimensional space, although they always retain a probability of interacting with classical objects at a definite location. Interaction between quantum properties and classical properties (including those of experimenters and their instruments) precipitates an objective collapse of the quantum object's wavefunction, as a result of the joint exercise of the relevant causal powers of the object and the instruments, and not because of the involvement of human consciousness and choice.

Here is how Nancy Cartwright describes this pluralist view:

> …quantum realists should take the quantum state seriously as a genuine feature of reality and not take it as an instrumentalist would, as a convenient way of summarising information about other kinds of properties. Nor should they insist that other descriptions cannot be assigned besides quantum descriptions. For that is to suppose not only that the theory is true but that it provides a complete description of everything of interest in reality.
> (Cartwright 1999, p. 232)

Thus, the hylomorphic interpretation combines features of both the old Copenhagen and newer "objective collapse" interpretations. It is a fully realist view about the microscopic, unlike Bohr's version of the Copenhagen interpretation, and it is

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[11] Grove's dissertation includes useful correctives to some of the philosophical mistakes (from an Aristotelian point of view) in Heisenberg's and Smith's treatments.

ontologically pluralistic, in contrast to other objective collapse theories. It admits a plurality of objective domains, and it doesn't treat wave collapse as a phenomenon explainable within the pure quantum domain, by some as-yet-unknown microphysical interaction. The hylomorphic interpretation fits naturally with the generalized quantum mechanics, to be discussed in Part III, in which quantum collapse can be predicted and explained within an algebra containing both quantum and classical observables.

Unlike the Copenhagen view, the PQHM interpretation fully embraces the reality of quantum objects and quantum states. That's an advantage, because the Copenhagen interpretation is vulnerable, as are all versions of anti-realism and instrumentalism, to the No-Miracles argument for scientific realism. The Copenhagen view leaves unexplained why the quantum mechanical formalism works, and it threatens to undermine all our inductive inferences. Why not take an anti-realist viewpoint about all our beliefs that transcend in any way our immediate experience? Copenhagen puts us on a slippery slope to phenomenalism.

In addition, the Copenhagen view suffers from being two narrowly dualistic, distinguishing the classical world from the quantum world. In contrast, the hylomorphic interpretation embraces a salutary kind of ontological *pluralism*, recognizing that the non-quantum or supra-quantum world is itself a "dappled" world (as Nancy Cartwright puts it), dividing naturally into multiple domains at multiple scales.

Pluralistic Quantum Hylomorphism shares two crucial advantages with the Copenhagen view. First, it embraces realism about classical objects and classical states, and so it can make sense of our experimental practices in a straightforward way. Second, it fits the actual practice of scientists well, who are in practice ontological pluralists (as Nancy Cartwright has documented).

6.2 Pruss's Traveling Forms Interpretation

On Pruss's picture, there is a single quantum wavefunction which describes the state of the whole of quantum reality and which evolves according to a unified, deterministic function (based on Schrödinger's equation). However, this quantum reality is not the whole of reality, nor does the macroscopic world supervene upon it.

As I have explained, this quantum wavefunction can (setting aside quantum field theory for the time being) be taken as ascribing potential positions to each of the world's quantum particles. Some of the potential positions of some particles are strongly correlated with those of other particles, the process of decoherence (mentioned above). This decoherence process can be thought of as delimiting a very large set of alternative consistent histories of the world's particles. On Pruss's view, just one of these histories has a metaphysically privileged status, forming the basis for the real composition of material bodies, including living organisms. Even though this history is not *microphysically* privileged, acting simply on a par with all other consistent histories in the uniform evolution of the quantum world, it is *ontologically* distinguished by the fact that it, and it alone, corresponds to a world of real composite objects. Pruss in effect uses facts about "special question of composition" (to use Peter van Inwagen's phrase) to single out one micro-history as the material basis for a world of macroscopic objects (van Inwagen 1995).

Although Pruss's world is microscopically deterministic, the macroscopic world is dynamically indeterministic, since the consistent history that underlies that world at one time can later "branch" into several, disjoint histories. The substantial forms of macroscopic objects travel together down just one of those branches, in a way that is not determined at the quantum level, and which may be undetermined at the macro level as well, although macroscopic agency (including acts of free will) may contribute to determining the direction of "travel". When a composite body interacts with quantum system and the branch splits into two new branches, the joint direction taken by the substantial forms must respect Born's rule, which determines the probability of the forms' taking any given branch to be the square of that branch's wave amplitude. This doesn't mean, however, that macroscopic propensities are wholly determined by microscopic probabilities. For example, the composite bodies and their macroscopic processes might induce correlations among micro-events that make those events' joint probabilities other than the product of their individual probabilities.

7 Three New Interpretations

In the last sixty years, physicits have developed three new interpretations of quantum mechanics to compete with the Copenhagen model: the "many worlds" or "relative states" interpretation of Hugh Everett, the pilot wave theory of de Broglie and Bohm, and a variety of objective collapse theories, including that of Ghirardi, Rimini, and Weber. These new interpretations might seem to blunt the argument against the straight road to microphysicalism that I developed in section 5. They all eliminate roadblock 1, which depended explicitly on the Copenhagen interpretation. Bohm's theory of quantum mechanics also mitigates roadblocks 2 and 3 (non-separable states and quantum fusion), by assigning definite locations at all times to each particle.

However, none of these interpretations reduce the significance of the remaining three roadblocks. In addition, both the many-worlds interpretation and Bohm's mechanics are ultimately inconsistent with microphysicalism, supporting a diametrically opposed metaphysical position, that of cosmic monism (in which only the whole universe is fundamental). The GRW theory (a version of objective collapse theories) actually entails the truth of ontological escalation as I've defined it.

On two of these three interpretations, it is not microscopic particles or punctual conditions of spatially-extended fields that constitute the fundamental entities of the world, but rather a single, unified quantum wavefunction, plus (in the case of Bohmian mechanics), a single indivisible system of point-particles. If there is, on the Everett interpretation or the deterministic Bohmian interpretation, any locus of causal power in the world, it is the world itself that bears those powers. We are indeed forced into a Parmenidean or Spinozistic monism, in which a single, isolated substance evolves according to its own immanent dispositions. From an Aristotelian point of view, this is every bit as objectionable as microphysicalism, being equally subject to the Phaedo's No-Agency argument (from section 2).

7.1 Priority Monism and The Everett Interpretation

This causal monism[12] is clearest in the Everett interpretation.[13] The cosmic wavefunction is the only fundamental reality, and so the only possible bearer of causal powers.

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[12] Strictly speaking, I will define cosmic monism in terms of fundamental properties and powers, rather than fundamental entities. By my accounts, monism is committed to the thesis that either (i) there is only one fundamental entity (the universe), which is the sole bearer of fundamental properties and powers, or (ii) all fundamental properties and powers are borne jointly (as a whole) by the plurality of all fundamental entities—so, there are no fundamental properties intrinsic to any individual thing or to any subset of fundamental things. Thus, my usage of the term is wider than that of Schaffer.

[13] There are anti-monist versions of the Everett interpretation, namely, the many-minds interpretation of Albert and Loewer (1988), the traveling-minds interpretation of Barrett (1995) and the traveling forms interpretation of Alexander Pruss, interpretations that avoid both of these difficulties. However, both the Albert-Loewer and the traveling-minds models require a strong version of Cartesian substance dualism, and the traveling-forms model is a version of hylomorphism, as we have seen in section 5.

Consequently, the Everett interpretation provides no relief for microphysicalism. It avoids the first roadblock (that of the Copenhagen interpretation) but does nothing to roadblocks two through five. Quantum states are still non-separable (roadblock 2), similar particles in an entangled system still seem to fuse indistinguishably (3), quantum field theory still creates problems for fundamantal micro-entities (4), and the teleology and holism of the Hamiltonian analysis are undisturbed (5).

7.2 Bohmian Mechanics: Determinism Entails Monism

Bohm's theory (in its standard, deterministic version) is in much the same position. The particles have only passive powers, and only as a unified system. There are no localized causal powers, whether active or passive. In the Bohmian case, it is clear that the particles do not constitute fundamental individuals, because they utterly lack active causal power, and their passive power of being moved by the pilot wave is in the form of a single, non-separable, or joint response to the wave's influence. For this reason, Bohmians often find it convenient to use a mathematical model in which there is a single "world-particle" that moves in a 6N-dimensional phase space (where N is the number of localized particles, and the six dimensions per particle give the particle's 3D location and momentum in our familiar space).

This could pressure toward monism could be resisted, however, by resort to my own arguments against the identification of supervenience and grounding from section 3. There I argued that we cannot simply infer that the A-facts are grounded in the B-facts from the mere fact that the A-facts supervene on the B-facts. And this is clearly the case in Bohmian mechanics: the positions of the individual particles supervene on the "position" of the world-particle (in 3N-space), but likewise the position of the world-particles supervenes on the positions of the individual particles in ordinary 3-dimensional space. Supervenience alone cannot tell us which is grounded in which (or whether both are grounded in some third thing).

However, if we combine a deterministic Bohmian theory with an anti-Humean "causal-powers" ontology, according to which causal powers are among the world's fundamental facts, then it seems clear that priority monism must result. There are no separable passive powers of movability that can be attributed in Bohm's theory to individual particles: the particles necessarily move as an indivisible system in response to the guidance of the pilot wave.

Nonetheless, there is an *indeterministic* version of Bohm's theory (see Callender 2007, Bohm and Vigier 1954, Bohm and Hiley 1993, Peruzzi and Rimini 2000; for a similar but non-Bohmian theory, Nelson 1985). This version is not compatible with all-out microphysicalism (since it still leaves the non-separable cosmic pilot wave in place), but it is consistent with hylomorphism and ontological escalation. These versions of Bohmian mechanics add a random or stochastic element to the Schrödinger equation for the guidance function, which can help to explain why the universe is able to reach "quantum equilibrium" (see Dürr et al., 1992), at which point observed statistics match quantum mechanical predictions (according to Born's rule).

7.3 GRW Theory and Ontological Escalation

GRW, in contrast with the Everett interpretation or deterministic Bohm theory, fits perfectly with the metaphysical model of ontological escalation and is therefore fully compatible with hylomorphism. The most recent versions of GRW are incompatible with microphysicalism, since they imply that it is complex wholes (as such) that precipitate (in an irreducibly holistic way) the objective wave collapses, and those wholes rarely (if ever) encompass the whole universe (perhaps they did, briefly, after the Big Bang). Once our physics has opened the door to causal/ontological escalation, there is not principled basis for excluding further escalation at the thermodynamic, chemical, biological, and even social-psychological-linguistic levels.

7.4 Refuting Cosmic Monism: The Causal-Powers Perspective

As we have seen, both Everett's interpretation and deterministic Bohmian mechanics requires a form of "priority" monism: the thesis that the only fundamental entity is the whole cosmos. Only the complete universe has fundamental properties or powers. Such monism comes at a very high metaphysical and epistemological cost. I will argue (1) that it is impossible to ground derived causal powers for sub-cosmic entities within this view, (2) that the resulting loss of causal powers in isolated systems deprives us of our best account of our knowledge of natural laws, and (3) that this loss of causal powers undermines the rational justifiability of sensory perception.

In this section, I will be drawing heavily on recent work in the development and defense of a causal-powers ontology. This includes the work of Harré and Madden (1975), Cartwright (1994), Ellis (2001), Heil (2003), Molnar (2003), Mumford (2004), and Bird (2007). It would be best to think of my aim in this Part to be the establishing of a conditional thesis: if an ontology of causal powers is our best account of human knowledge, then hylomorphic interpretations of quantum mechanics are clearly superior to those committed to cosmic monism.

7.5 The Impossibility of Deriving Powers of Sub-Cosmic Entities in Cosmic Monism

It is easy to obtain *derived* causal powers for macroscopic entities under the assumption of microphysicalism: any spatial arrangement of powerful microscopic entities gives rise to derived powers for the corresponding composite (assuming that there is one). The resulting composite entity will have, as its derived powers, whatever joint dispositions result from the combined action of the microscopic parts.

There is no counterpart to this composition-of-agency model for cosmic priority monism (the view that all fundamental causal powers belong to the universe). There is no natural way to divide the powers of the whole cosmos into derived powers of its proper parts. The best we can do is to look to various counterfactual conditionals: if part x were to act in way F, then part y would act in way G. Use the usual Stalnaker-Lewis technique for evaluating such counterfactuals: find the smallest modification to the evolution of the cosmos that verifies the antecedent and see if it also verifies the consequent.

However, there are compelling objections to any such counterfactual account of causal powers and dispositions (whether fundamental or derived). First, as Alexander Pruss has shown, the counterfactual strategy cannot ground an objective direction of time (Pruss 2003), while all causal powers presuppose a natural direction from past to future. In addition, causal powers require objective normality conditions for their exercise, conditions which counterfactual conditionals cannot provide (Koons and Pruss 2015). Moreover, there are many other well-known problems with counterfactual accounts of causation and causal powers: finking, reverse finking, masking and mimicking, late preemption and preemption by trumping (see Koons and Pickavance 2014, chapter 3 for a summary).

7.6 Measuring Nature's Capacities

Monists cannot make use of Nancy Cartwright's model (Cartwright 1994) of the interaction of the causal powers of the investigator with the causal powers of an intentionally isolated system, since there are no such causal powers, and no such isolation is possible in an indivisible universe. The only way for monists to understand scientific inquiry is in strictly neo-Humean terms, which ultimately undermines the rationality of induction (see Koons and Pickavance 2014, chapter 3).

8 The Plurality of Interpretations: A Permission Slip to Hylomorphists

I don't imagine that any of the considerations I raised in section 7 are sufficient to rule out the many-worlds interpretation or to force the other two in an explicitly hylomorphic direction. However, the very fact that we have three competing metaphysical theories about the foundations of quantum mechanics provides a striking contrast between the pre-quantum and post-quantum worlds. There was no question about the metaphysical meaning of the classical world of Newton, Maxwell, and relativity. Then we had the straight road to microphysicalism (as I described in subsection 5.1).

The situation now has radically changed. There is no consensus about what quantum theory tells us about the world, and all of the familiar answers (the Copenhagen interpretation and the three modern theories) are incompatible with a strict microphysicalism. Hylomorphism is now viable as an account of the natural world, in a way that it simply wasn't from the Scientific Revolution until the 1920's. As Jonathan Schaffer (2010) has argued, cosmic monism is also a real competitor. I contend that it is primarily hylomorphism's superior account of the possibility of human knowledge and agency that will carry the day.

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