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The Two Faces of Semi-Physicalism: A Response to Hans Halvorson

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Abstract. This paper responds to Halvorson's reflections on hylomorphism by addressing its quantum application (Koons and Simpson) and contextually emergent physics (Ellis and Drossel). It also critiques physicalist interpretations of quantum mechanics and argues for the fundamental nature of thermodynamic phenomena. Koons, Simpson, Ellis and Drossel defend hylomorphism as a framework that challenges dogmatic semi-physicalism. They examine causal pluralism, semantic indeterminacy and the limited validity of quantum mechanics, emphasising the role of micro and macroscopic elements in shaping a consistent worldview.

Keywords: quantum, emergence, physicalism, wave function, thermodynamics, hylomorphism, measurement problem.

Contribution. We offer novel philosophical and scientific reasons for denying the claim that there is a single quantum wavefunction for the universe on whose state all natural facts supervene.

Use of AI. The authors declare no use of AI.

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Introduction

We would like to thank Hans Halvorson for his thoughtful reflections on the revival of hylomorphism in philosophy, on the work of Robert Koons and William Simpson concerning the application of hylomorphism to quantum theory, and on the contextually-emergent physics of George Ellis and Barbara Drossel, which both Simpson and Koons have suggested may admit a hylomorphic interpretation. Our response is divided into three parts: the first part is by Koons and is based on the hylomorphic approach to quantum chemistry he has been developing over the course of the last ten years; the second part is by Simpson and draws on his recent work on hylomorphism and primitive ontology approaches to quantum mechanics; the third part is by Drossel and Ellis, which comments on the implications of their local wavefunction approach to quantum mechanics and thereby responds to Halvorson, Koons, and Simpson.

I

As I (Koons) reflect on Halvorson's remarks, I detect two incompatible points of view in evidence. In effect, there are two quite distinct Hans Halvorsons: one who comes close to embracing hylomorphism (let's call him "Halvorstotle") and another who remains wedded to physicalism ("Demovorson", combining 'Democritus' with 'Halvorson'). I'd like to persuade the real Hans Halvorson to stand up and embrace the first perspective and eschew the second.

Halvorstotle defends causal pluralism. Causal pluralism is a central tenet of Aristotelian hylomorphism, in contrast to the causal monism of physicalism. It is not, however, entirely clear what Halvorstotle means by 'causal pluralism'. A pluralism about causation must be a pluralism about causal powers—in particular, a pluralism about the metaphysically fundamental causal powers to be found in the world. To suppose that all the causal powers that exist are fundamentally grounded in the activity of physical powers, however, is to embrace a monistic metaphysics, not a pluralistic one.

A causal pluralist, as opposed to a mere dualist, will suppose that there are fundamental causal powers in multiple domains—more than two. They might suppose, for instance, that there are fundamental chemical, thermodynamical, and biological domains, as well as powers in the microphysical and personal domains. Since things with chemical, thermodynamical, and biological natures are wholly composed of microphysical things, we immediately face the question of the relationship between the powers of wholes and the powers of parts. Paul Feyerabend recognized that quantum mechanics requires 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 interpre-

> tations or suitable approximation methods to solve hairy cases; we 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)

At this point, Demovorson shows his face. He appeals to the universal composition of middle-sized things by "smaller quantum-mechanical things". Demovorson supposes that the hylomorphist must deny that middle-sized objects are "quantum-mechanical things" at all—that is, Domovorson supposes that hylomorphists deny that middle-sized objects have "quantum-mechanical descriptions" (pp. 6-7). He supposes that hylomorphists must say that quantum mechanics has "limited validity," in the sense that middle-sized objects must "violate the laws of quantum mechanics," and that there must be predictions of quantum mechanics that are "wrong."

In each of these cases, Demovorson is simply assuming the very issue that is at stake. He is assuming that all causal powers must have a complete, bottom-up explanation in terms of quantum mechanics. Standard quantum mechanics does not take into account the force of gravity. Does this mean that quantum mechanics is falsified whenever an apple falls from a tree? Surely not.[1] Even granting that quantum mechanics has universal validity, it does not follow that all causal interactions have a quantum-mechanical grounding. And it does not follow that, simply because a middle-sized object has a quantum-mechanical description in terms of Hilbert spaces, the middle-sized object is exhaustively described in this way. In fact, Halvorstotle explicitly denies that this is the case, at least in the case of human agents.

Demovorson speaks rather innocently about "laws of nature," as if the job of science were to discover universal, exceptionless generalizations

[1] My point is unaffected by the possibility that someday we might find a theory of everything (a version of string theory, perhaps) that encompasses both gravity and quantum phenomena. I'm talking about quantum theory (including QFT) in its present form, which clearly does not include gravitational effects. If physicalists are allowed to appeal to some ideal theory of the future, the same courtesy should be extended to hylomorphists. In neither case does admitting that our current quantum theory has limited application represent a kind of anti-scientific or anti-empirical stance. And the history of science gives me confidence that string theory or loop gravity or whatever unification of QM and gravity will itself have a limited domain of application.

that are supposed somehow to explain all natural phenomena. But this a picture that isn't popular among metaphysicians today, and for many good reasons (missing 2007, Cartwright 2017, Demerast 2017). First of all, as Bas van Fraassen pointed out (van Fraassen 1989), it's mighty difficult to understand what laws of nature are and how they are supposed to explain anything. Laws of nature are some kind of Platonic object, like a Fregean proposition, and it's mysterious how such objects, just by being true, could somehow explain ordinary, concrete events. Second, as Nancy Cartwright has demonstrated, practicing scientists don't actually deduce phenomena from laws of nature and initial conditions alone (Cartwright 1983). Instead, a law of nature is taken as a kind of stand-in for some naturally-realized causal power, and the explanation explains when some regularity within the phenomena can be (under appropriate conditions) related to that law. Finally, as Cartwright has also emphasized, scientific discovery does not proceed by passively noting certain exceptionless regularities and baptizing them as "laws of nature" (Cartwright 1994). Instead, we actively intervene in nature, building what Cartwright calls "nomological machines," through which we can control and isolate one particular form of causal power.

Thus, there is no reason to suppose that every phenomenon can be somehow deduced (even in principle by a Laplacian super-intelligence) from initial conditions. This gap between laws and the complex phenomena of nature does not involve supposing that particular laws, like the laws of quantum mechanics, are ever "violated" or entail "false predictions", as Demovorson presupposes. This worry is generated by a false expectation of how laws of nature should work. If by "limited validity" Demovorson simply means that quantum mechanics provides a complete explanation for all phenomena, then *all* laws of nature have limited validity.

This is all especially true in the case of quantum mechanics. The very form of the theory points to its incompleteness. What it predicts are certain probabilities, probabilities of events which are themselves described in non-quantal terms. It wouldn't make much sense to suppose that what the laws of quantum mechanics predict are simply the probabilities of other probabilities, and so on ad infinitum. Halvorstotle, rightly following Bohr at this point, recognizes this problem. As Halvorstotle states, quantum mechanics introduces a "description problem," a problem that had no counterpart in pre-quantum, classical physics. We can't say what would count as a "violation" of quantum mechanics until we have given some sort of account of what quantum mechanics predicts, and when does it do so. This is where the contextual emergence account of Drossel and Ellis, we believe, may prove valuable to hylomorphists. It provides us with a model for making sense of Bohr's two-domain account of the interpretation of quantum mechanics. And Halvorstotle should therefore be a staunch defender of it or something very like it.

Here Demovorson makes a passing suggestion, which strikes me (Koons) as an obvious non-starter. Demovorson seems to assume (along with other physicalists) that non-physical descriptions (like those of human consciousness and agency) toothlessly supervene on the quantum-mechanical description of the world, and do so in an extremely (perhaps infinitely) complex way, so that the quantum states that share a description in terms of human agency and intentionality correspond to an infinite disjunction of micro-physical descriptions, irreducible to any simpler representation at that level. That is, such non-quantal descriptions represent a kind of coarse-graining of the quantum-mechanical descriptions of particles, a coarse-graining that does not correspond to any novel forms of causal power or nomological necessity.

There is a deep problem with Demovorson's suggestion. His proposal constitutes a kind of epiphenomenal supervenience of our ordinary, quasi-classical world on an underlying, purely quantal world. This means that there is a unique many-one mapping of emergent descriptions on quantum-mechanical descriptions. There are no fundamental causal connections among the entities described by the emergent vocabulary: at best, there are stable counterfactual-conditionals relations among emergent-world propositions, which are explainable entirely in terms of the causal powers represented by quantum dynamics.

What *grounds* the correct mapping of the emergent descriptions onto the quantum descriptions? Any theory of the emergent world that can be mapped in one way onto the quantum world can also be mapped an infinite number of other ways, while preserving emergent-level truth, including the truth of emergent-level counterfactual conditionals. This is what Hilary Putnam's model-theoretic argument for semantic indeterminacy demonstrated (Putnam 1980, 197 see also Newman 1928 and Koons 2018, 78–93). As a consequence of this radical indeterminacy, any logically consistent story expressed in the emergent-world vocabulary can be mapped onto any state of the quantum world (so long as the cardinality of the domain of objects is the same). So, there will be "real" emergent worlds (as real as ours) corresponding to the Harry Potter stories or the Homeric epics.[2] To make our emergent world uniquely real, there must be some coarse-graining of the quantum world that is natural and objective (non-conventional), and this coarse-graining must make room for the exercise of fundamental causal powers at the emergent level. Only in this way can we restrict the mapping to provide a uniquely objective truth to the emergent world.

In fact, Demovorson's physicalism cannot even provide grounds for a unique subjectively-based coarse-graining. How do our emergent-level descriptions connect with the right quantum-mechanical disjunctions, if they generally correspond to badly-behaving infinite disjunctions? We can't contemplate and discriminate among literally infinite disjunctions of the kind Demovorson posits. If we suppose that the right coarse-graining tracks the presence of distinctive qualia, we face the problem that such qualia must (if physicalism is true) be causally inert, and so cannot influence our thinking. Moreover, phenomenology alone cannot tell us which qualia should be associated with which quantum states. Qualia do not come with their own physical satisfaction conditions on their face, and so they cannot help in escaping Putnam-like indeterminacy. So, even a kind of epiphenomenal mind/body dualism won't solve the problem. Our thoughts, when expressed in the emergent-world vocabulary, will be

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2 We can always impose, by sheer stipulation, that a "real" emergent world satisfies certain physical principles, like time invariance or the approximate truth of Newtonian mechanics. But such a stipulation removes these principles from the domain of empirical science, making them true by stipulation and not confirmed by evidence.

so indeterminate that we cannot assign truth-values to them, no matter what is happening at the quantum level.

Demovorson's viewpoint could be expressed as one embracing the semantic non-reducibility of psychology to quantum physics, while permitting ontological reduction.[3] As my colleague Dan Bonevac has put this, such merely semantic non-reducibility amounts to "reduction in the mind of God"(Bonevac 1995, 124-139). If the mind is ontologically reducible to the quantum level, how important is it that such a reduction requires infinite representational and computational resources?

Even more fundamentally, such merely semantic non-reducibility introduces exactly the sort of semantic indeterminacy that the Putnam paradox describes. Our linguistic practices involve only finitely many data points, which are therefore compatible with a wild variety of infinitary interpretations. What grounds the correct infinitary reduction of our mental vocabulary to that of quantum theory? Without a precise grounding, the semantic indeterminacy implies epistemological instability. How can we know by introspection what we are thinking or experiencing, if our mental vocabulary is radically indeterminate (like an extreme case of semantic vagueness)?

To solve this problem, we have to suppose that emergent-level descriptions (say, descriptions at the level of thermodynamics, chemistry, or biology) correspond to metaphysically fundamental causal powers and modalities, powers that interact (via Born's rule) with the quantum realm and its Schrödinger dynamics. We can then have objective wavefunction collapse without conjecturing about any unobserved, bottom-up collapse mechanisms (as in GRW). In fact, such purely bottom-up mechanisms would not help us much, since they leave us with an unresolved ontological gap between the quantum world and the chemically and thermodynamically determinate world of observers and their instruments.

Demovorson claims that we shouldn't abandon the "universal validity" of quantum mechanics without empirical grounds for doing so. As I mentioned, gravity provides plenty of grounds for this, but in addition, all the facts we observe about temperature, entropy, phases of matter, and

[3] Koons wishes to thank Pui Him Ip for this suggestion.

chemical composition gives us overwhelmingly good empirical grounds for denying that everything is, even in principle, explainable in quantum terms. Demovorson assumes that the irreducibility of thermodynamics to quantum mechanics is merely a matter of convenience or computational complexity. Or that it is simply a reflection of our current state of ignorance.

However, both Barbara Drossel and I (Koons) have provided arguments that thermodynamical phenomena are not even in-principle reducible to quantum mechanics (Drossel 2015, 2017, Koons 2021a, 2021b, 2022). We have given good reasons for thinking that these thermodynamic facts do not even supervene on the facts statable in the limited vocabulary of quantum theory (even RQFT). These facts are well-understood by many philosophers of chemistry and theoretical chemists, even if they have largely been ignored by philosophers of "fundamental" physics. Demovorson doesn't respond specifically to any of those arguments. If we are right, then we have empirical evidence for the limited applicability of quantum mechanics whenever we observe an ice cube melting or a tablespoon of salt dissolving in water.

If Demovorson's physicalism were correct, then we could represent every state of the world by means of a vector in a non-separable Hilbert space, with its corresponding type-I algebra. Halvorson is a world-leading expert on algebraic quantum field theory: he knows that this is not in fact the way quantum theorists proceed (Sewell 2002, 2-3). Instead of following physicalism's injunction, working physicists take the descriptions of the states to the thermodynamic or continuum limit, resulting in a representation with multiple superselection sectors. The Stone-von Neumann theorem of 1935 necessitates the infinite structure introduced by the continuum limit. Any "realistic" representation (with a finite number of particles or other sub-systems) is trapped in a type-I algebra, with its mutually non-commuting observables (lacking a non-trivial center). The continuum limit is not introduced to make our calculations simpler or to exclude negligible interfering factors (like friction). It's used in order to introduce additional mathematical structure into our representations, structure that is needed to represent such important features as temperature, entropy, and distinct phases of matter. These additional features cannot be captured by any separable representation of the quantum state (i.e., a bottom-up representation in terms of the actual particles and other micro-constituents of the whole). Nonetheless, Demovorson insists that these additional features must ultimately supervene upon the micro-ontology. Why? Instead, I suggest that they are fundamentally holistic features of the macroscopic substances involved, corresponding to the top-down influence of an Aristotelian form. On an Aristotelian account of the world, the natural world is tessellated by substances, both organic and inorganic.

Barbara Drossel offers a distinct but complementary argument for the incompleteness of quantum mechanical descriptions, arguing that the statistical assumptions undergirding statistical mechanics can be defended only if every quantum-mechanical description is accurate only to a finite degree of precision (Drossel 2015, 49-52). This leaves upon the possibility of genuinely top-down causation, without any violation of the now-qualified laws of Schrödinger dynamics.

Drossel has also pointed out that attempted "derivations" of thermodynamics from finitary quantum mechanics rely on a localization of atoms and molecules that cannot be justified from a bottom-up, pure-Schrodinger-dynamics perspective (Drossel 2017, 2-3). Unitary quantum dynamics is inconsistent with the appearance of spontaneous symmetry breaking, which is essential thermodynamics and chemistry (Drossel 2017, 6-7; Strocchi 1985, 117-8; Sewell 1986, 19, 34; Hendry 2006, 215-6). Simple, finitary quantum mechanics lacks the sort of causal irreversibility that is required for thermodynamics, a point earlier advanced on behalf of pluralism by Ilya Prigogine (Prigogine 1997, 149). In modeling Planckian blackbody radiation, physicists rely on models in which "phonons are modeled as pretty well localized (quasi-) particles that interact locally" (Drossel 2017, 8), inconsistent with the pervasive and persistent superpositions of unitary Schrödinger dynamics. Finally, the theory of thermalized quantum systems presupposes facts about the very thermodynamic properties that physicalists assume it can explain away (Drossel

2015, 52; 2017, 8). Decoherence theory, in particular, relies on facts about temperature, entropy, and phases of matter.

Philosophy of physics has been, for too long now, in the grip of a dogmatic adherence to physicalism, or at least to the sort of semi-physicalism exemplified by Halvorson. Yet physicalist interpretations of quantum mechanics are all philosophically problematic, and semi-physicalism is a two-faced philosophy which threatens incoherence on closer examination. Hylomorphism combined with the contextual emergence theory of Drossel and Ellis could help to shake philosophers of physics out of that dogmatic slumber, providing them with an enriched toolbox with which to untangle the mysteries of both the quantum world and our emergent experience of it. In the following Section, Simpson responds to a specific theoretical objection which Halvorson raises against Drossel's and Ellis's approach to quantum mechanics.

II

In taking the baton in this response to Hans Halvorson, let me (Simpson) begin by observing that hylomorphism is not one theory but rather a *family* of theories that share a common patrimony in Aristotle's account of composite objects (for a taxonomy, see Simpson 2023a). Hylomorphists analyze physical objects in terms of both *matter* and *form*, but they hold a variety of views concerning the ontological status of the analysans. Furthermore, 'quantum hylomorphists' who seek to apply hylomorphism to the metaphysics of quantum mechanics are not wedded to any single interpretation of quantum mechanics. They have engaged a variety of interpretations, including Many Worlds theory (Pruss 2018, Koons 2018), de Broglie-Bohm theory (Simpson 2021a, 2021b, 2023b, 2024, Simpson & Pemberton 2022), Adrian Kent's theory (Verrill 2023), and contextual wave function collapse theory (Simpson 2021b). The hylomorphic revival in philosophy is a broad church shaped by a wide variety of concerns. What we are discussing in this conversation with Halvorson is something more specific.

Halvorson focuses on a single type of hylomorphism, which I have classified elsewhere as 'powerist' and 'constituent-based': there are physical things which are *constituted by forms* independently of how we conceptualise them, and their forms confer upon them certain *causal powers* (Simpson 2023a). He also singles out Ellis's and Drossel's contextual wave function collapse theory (CWC theory) for criticism (Drossel & Ellis 2018), which has some attractive features for hylomorphists who are seeking to underscore the reality of middle-sized things (Simpson & Horsley 2022). In particular, CWC theory ascribes to middle-sized things irreducible causal powers to act upon smaller things, causing changes at the microscopic level which otherwise would not take place. Ellis writes: 'the quantum to classical transition is characterised by contextual wave-function collapse shaped by macroscopic [middle-sized] elements that can be described classically' (Ellis 2024, 1). According to this construal of quantum theory, the quantum wave function of a microscopic system is caused to collapse by interacting with middle-sized systems which have thermal features that are not explained by quantum mechanics.[4] Such systems are characterised by 'heat baths' which (Drossel argues) cannot be assigned a wave function either in principle or in practice (Drossel 2017). According to Drossel and Ellis, quantum mechanics does not extend to these larger physical systems. Quantum mechanics can be applied locally everywhere, if we consider the world piecemeal, but quantum mechanics does not extend to arbitrary middle-sized objects, in the sense that each of its pieces may be assumed to compose a single, unified quantum system. Neither heat baths, cats, nor the cosmos as a whole are properly characterised by a *single* wave function (Ellis 2024).

Halvorson, *in persona* Halvorstotle, says he 'agree[s] with the spirit behind this approach to quantum mechanics'. He thinks we should treat middle-sized things as being just as real as micro-sized things. However, Halvorson *in persona* Demovorson, claims it falls foul of the 'quantum description problem'. He believes this problem has been solved by propo-

[4] In CWC theory, 'observation' is distinguished from 'wave function collapse'. In other words, there does not have to be a scientist making a measurement in order for the wave function to collapse.

nents of a rival collapse theory that does not endow middle-sized things with causal powers: namely, the spontaneous collapse theory proposed by Ghirardi, Rimini and Weber (GRW theory) (Ghirardi et. al. 1986). In the remainder of this response, I (Simpson) shall confine myself to discussing a solution to the quantum description problem known as 'the primitive ontology approach' that has been taken up by GRW theorists, and to challenging Halvorson's claim that CWC theory is unable to avail itself of a similar solution. Halvorson thinks hylomorphists should not use CWC theory because it has 'internal problems'. Ironically, I think the internal problems which Halvorson identifies with CWC theory can be solved by applying a hylomorphic version of the primitive ontology approach to CWC theory. I do not claim that my solution is a solution which all hylomorphist would wish to embrace, and I suspect it is more *metaphysical* than either Drossel or Ellis would like, but I think it goes at least some of the way toward addressing the problem that Halvorson has raised. I will then call attention to a different problem that CWC theory poses for quantum hylomorphists which I consider to be more pressing.

So, what is the difficulty which ought to disqualify CWC theory from consideration, according to Halvorson? The quantum description problem he presses upon us is related to the famous 'measurement problem' of quantum mechanics. Roughly: whilst microscopic systems can have quantum states which are superposed, there are states of middle-sized things which are never superposed. For example, the pointer on a measuring device being used to measure the 'spin' of a particle is never in a superposition of pointing both up *and* down. Some versions of quantum mechanics, like GRW theory and CWC theory, seek to account for the possibility of definite measurement outcomes by appealing to a physical mechanism which compels the quantum state (wave function) to 'collapse' into a state corresponding to a definite outcome: the particle either collides with the 'up' detector *or* the 'down' detector of the measuring device, and the pointer on the measuring device either points up *or* down. The quantum description problem, Halvorson explains, concerns 'how we describe the quantum-mechanical objects whose wavefunctions are supposed to collapse'. It challenges us to state clearly 'how to read the quantum formalism in all circumstances, whether or not some measurement is being performed'. Both GRW theory and CWC theory offer solutions to the measurement problem which involve dynamical processes, in which some initial way that the world is W_{t0} (prior to a collapse in the wave function) gives way to some subsequent way that the world is W_{tf} (following a collapse in the wave function). As Halvorson points out, 'For this kind of story to be coherent, it must mean that earlier states… describe a way that the world can be. So what is this way that the world is when the initial state is, say, a superposition of going through the top slit and going through the bottom slit?'

Whilst Ellis and Drossel have remained quiet concerning the ontology of the wave function, proponents of GRW theory have been busy solving the quantum description problem, providing a positive account of the reality that quantum mechanics describes. One solution that Halvorson discusses involves treating the quantum state as a function on a high dimensional configuration space in which it is defined, where this function describes an actual mass density distribution in this space. According to this approach, there is a definite way the world is, specified by a mass density distribution in a high-dimensional space, and the wave function describes how this distribution evolves through time. I think Halvorson is right to say that proponents of CWC theory would find this solution to the quantum description problem uncongenial, since they regard middle-sized objects in ordinary space as real and having irreducible causal powers. 'They would have an entirely new problem of showing how these two spaces interact with each other — and this is precisely the kind of problem that hylomorphists claim not to have'.

However, this solution to the quantum description problem has features which have turned out to be unattractive to philosophers who are sympathetic to GRW theory too. After all, quantum measurements are conducted by scientists using middle-sized objects in ordinary three-dimensional space (or four-dimensional spacetime), but this approach to quantum mechanics shifts the theatre of observation and experimentation away from ordinary physical space to the high-dimensional space of the wave function. This raises the problem of how middle-sized objects, like scientists and their measuring devices, are supposed to emerge out of the high-dimensional field. What sort of reality do middle-sized things possess, and how are scientists able to perceive and interact with them? As Brad Monton has pointed out, the high-dimensional space of the wave function does not possess any structure indicating how its points should map onto particle configurations in ordinary three-dimensional space, or any other kinds of objects in three-dimensional space for that matter (Monton 2002, 2006, 2013). There have been sophisticated attempts to recover macro-objects from the wave function's dynamical behaviour instead, by adopting a functionalist approach to macro-objects (Albert 2015), yet the physical reality of macro-objects cannot be secured simply by stitching together some fragments of a field in a high-dimensional space whose dynamics exhibits the same mathematical structure as a system of particles.[5] After all, we can easily find systems in ordinary physical space which admit models of their dynamical behaviour that share the same mathematical structure, even though the systems which we are modelling are physically very different (such as the textbook case of spring on a hook and an RLC circuit, where the dynamical quantities of the system are governed by a differential equation of the same form).

For reasons such as these, many philosophers who are sympathetic to GRW theory have adopted a 'primitive ontology approach' to GRW theory instead (Allori 2013). According to the primitive ontology approach, the mass density distribution exists in ordinary *three-dimensional space*, rather than the high-dimensional space of the wave function, and the wave function enters the account through the *nomological role* it plays in specifying the dynamics of this primitive distribution of matter. This is a general approach to quantum mechanics which is committed to there being a definite way the world is, but which avoids reifying the high-dimensional space in which the wave function is defined. The same approach can be taken to de Broglie-Bohm theory (Allori et. al. 2008), although this theory offers a different solution to the measurement problem; one in which the wave function does not literally collapse. In this

5 For another sophisticated attempt to recover macro-objects from a high-dimensional field, see (Alyssa 2021).

case, the primitive distribution of matter consists of particles, and the wave function plays a nomological role in choreographing their trajectories through ordinary physical space.

However, there is more than one way of spelling out the nomological role of the wave function in the temporal development of the matter. Esfeld favors a Humean account of laws, arguing that the wave function should be conceived as part of a Humean 'Best Systems' account (Esfeld 2014). According to the Best Systems account, as David Lewis described it, a law is nothing more than a descriptive summary of how the basic constituents of the physical world are arranged: a 'contingent generalization that appears as a theorem (or axiom) in each of the true deductive systems that achieve a best combination of simplicity and strength' (Lewis 1973, 73). Clearly, the wave function for the quantum Humean does not represent any addition to the primitive ontology, over and above the primitive distribution of matter. It is not a separate entity in a high-dimensional space which *interacts* with the particles in ordinary space.

Other philosophers who have considered the primitive ontology approach to quantum mechanics, however, believe that the attempt to Humeanise quantum theory has run into difficulties (Simpson 2021c), and that a 'powerist' (or 'dispositionalist') account of laws enjoys advantages over the Humean account (eg. Simpson 2023b). According to powerists, laws express the essence of causal powers (Bird 2007). The relevant power is instantiated by the primitive distribution of matter and the wave function *represents* this power. In this account, the wave function represents something which is immanent to the world of middle-sized objects in ordinary three-dimensional space, rather than being an entity in a high-dimensional space. I have argued elsewhere that, in order to explain the persistence and transworld identity of the causal power which is represented by a wave function, we should think of the matter which instantiates this power as being *in-formed* – in a hylomorphic sense (Simpson 2021a, 2023b).

If the CWC theorist adopts a primitive ontology approach to quantum mechanics then, contra Halvorson, they will not have to face the problem of explaining how two distinct kinds of objects belonging to two distinct physical spaces are supposed to interact with each other; a cosmic version of the causal nexus problem which confronts certain dualist accounts of the soul in the philosophy of mind. According to the approach I have just outlined, a middle-sized thing that exists in ordinary physical space, which has features that are described by classical mechanics, is comprised of portions of matter that also exist in ordinary physical space, which have features described by quantum mechanics. CWC theory does introduce a complication. According to Ellis, 'complex systems… cannot be described by a *single* wave function: only local wave functions can exist, rather than a single wave function for a living cell, a cat, or a brain' (Ellis 2024, 1; emphasis added). These different parts of a middle-sized thing will have different powers represented by different wave functions. Nonetheless, all of these parts exist in ordinary physical space, and all of their powers are immanent within the world of middle-sized things. The primitive ontology approach that has been adopted by some GRW theorists, when it is combined with hylomorphism, can thus be extended to CWC theory, providing a way of solving the quantum description problem.

However, I do foresee a different sort of challenge facing quantum hylomorphists than the one which Halvorson has raised. Suppose the microscopic domain is patchy in the way that CWC theory conceives (Ellis 2022), such that different wave functions characterise different local patches, and that a middle-sized object, such as a human being, is comprised of many such patches. Ellis conceives of middle-sized things as 'modular hierarchical structures' in which upper levels constrain lower level modules (Ellis 2024). According to the kind of hylomorphism in view in this discussion, the physical things comprising the world are constituted by matter and form, and the forms of these physical things confer upon them certain causal powers (Simpson 2023a). A hylomorphist would like to say that, if a middle-sized thing has causal powers which cannot be reduced to the powers of its parts (or lower level modules), it is because it has a substantial form responsible for coordinating these powers. Not everything in nature has a substantial form, and hylomorphists typically insist upon the sparsity of substantial forms: we can often understand the causal powers of composite entities in terms of the powers of their parts and how they are arranged. In the case of a human being, however, or of other living beings, the causal powers of the whole are not reducible to the powers of its parts. A human being has a substantial form which is identical to its soul. This is a different conception of the soul than Descartes', in which body and soul are conceived as two separate and distinct substances with their own properties and powers, and in which the soul of a human being acts on their physical body as an efficient cause.[6] In a hylomorphic account of a human being, the causal powers of a human body derive from this human being's substantial form.

But here's a difficulty for hylomorphism: according to contextual wave function collapse theory, the heat bath of a middle-sized system *derives* its classical features (ie. its determinate, non-quantum-mechanical features) from interactions with its 'environment'. There are two reasons why CWC theorists make this claim. First, events in which quantum particles are localized (for example, in a measurement event where a particle is detected on a screen) are irreversible, stochastic, and non-linear; and irreversibility is always accompanied by an increase in entropy. Secondly, no increase in entropy is believed to be possible in a closed system at equilibrium. So it seems that, according to contextual wave function collapse theory, the 'classicality' of a physical system is an *extrinsic* feature of the system, inasmuch as this is something it derives from its environment, rather than something it possesses *of its own nature*. This does not fit the traditional hylomorphist picture we find in Aristotle's philosophy of nature, in which the world is comprised of distinct physical objects, and these objects derive their physical properties from their immanent forms. A hylomorphist would like to say that the classical features of middle-sized things like humans and animals are *intrinsic* features.

Yet this outsourcing of 'classicality' to the environment, if I may so describe it, leads Drossel and Ellis into a potential regress: if the heat bath of a middle-sized system (which is supposed to have the power to collapse

6 The hylomorphic account avoids the pairing problem for Cartesian dualism: if there are non-physical souls in *addition* to particles, what *connects* individual souls to particular pluralities of physical particles at given times?

the wave function of a quantum system) is not an *intrinsically* classical system, then what holds true for the particles comprising the quantum system must hold true for the particles comprising the heat bath of the middle-sized system. The particles comprising the quantum system are supposed to derive any classical features they acquire from their interaction with the heat bath, but it seems the heat bath is also supposed to derive its classicality from interactions with the larger physical environment in which it is embedded. In other words, one has to appeal to something *outside* of a middle-sized system in order to account for the classicality and localization of its physical components too. At what point, however, does one stop appealing to something *outside* of a physical system – ie. to ever larger physical systems – in order to account for any of the world's classical features?

One way to put a stop to this regress is to insist that there must be some *intrinsically* classical features of the cosmos as a whole.[7] For the contemporary hylomorphist, I believe, this requires an adjustment in the picture of the world they have inherited from Aristotle: they should be willing to apply hylomorphism to the cosmos as a whole – the cosmos is also a hylomorphic entity constituted by matter *and* form.[8] Does this mean that the cosmos itself is a kind of Aristotelian substance with its own substantial form? Possibly, and this idea is worth exploring, but there may be other ways of understanding the concept of a cosmic form. A hylomorphist can admit different kinds of *orders* within nature which exhibit different degrees of *unity*: there is the unity of a substance, for instance, such as a living being, which constitutes a strict kind of unity. Aristotelians typically insist that substances cannot contain other substances as parts though Scotists demur. But there are lesser kinds of unities too, such as the unity of a city. Koons has argued that the members of such a collective share a 'group form' (Koons 2024, Simpson & Koons 2025), which is not the same as a substantial form, and that the members of such a group exercise irreducibly joint causal powers. Suppose the world

7 Roger Penrose has speculated that gravity is ultimately responsible for the collapse of the wave function (Penrose 1996).
8 I call this the theory of 'Cosmic Hylomorphism' and have explored different versions of this theory: eg. (Simpson 2021a, 2021b, 2024), (Simpson & Pemberton 2022).

has a 'cosmic form' which determines certain irreducible properties of the cosmos as a whole, whether this form is conceived as a substantial form or a group form. In that case, the cosmic form could play a constitutive role in determining the physical properties of the parts of the cosmos, including middle-sized entities like human beings – just so long as it does so *jointly* with the substantial forms of these middle-sized entities (Simpson & Koons 2025). The cosmos might be more tightly knit together on this view than Aristotle originally envisaged (Simpson & Koons 2025, Simpson 2024). However, philosophers need not demand the *reduction* of middle-sized things to smaller things (like particles) or to larger things (such as the cosmos as a whole) in order to specify a fundamental ontology. Nor need we submit to the Jekyll and Hyde of semi-physicalism, like Halvorson, if we find neither of these alternatives satisfactory. Hylomorphism, suitably updated, provides us with a middle way to avoid these extremes.

III

In the third and final part of this response to Halvorson, we (Drossel and Ellis) offer some comments on the discussion between Halvorson, Koons and Simpson; first, from the perspective of a condensed matter physicist (Drossel); second, from the perspective of a cosmologist (Ellis). Both of us collaborated in articulating the contextual wave function collapse theory to which Halvorson, Koons and Simpson have all referred. Although neither of us is a professional philosopher, we recognise the need for the kind of ontological and conceptual clarity which philosophers of physics like Halvorson are seeking, and we find ourselves in agreement (for the most part) with the response that the philosophers Koons and Simpson have made in rising to Halvorson's challenge. We think there is a danger of Simpson's application of hylomorphism to CWC theory being dismissed out of hand, however, because of a curious disparity between the way in which philosophers of physics think about 'quantum mechanics' viz-à-vis the way that quantum theories are used in practice.[9] Let us explain.

[9] Simpson first suggested a hylomorphic interpretation of CWC theory in his doctoral thesis (Simpson 2020).

I (Barbara Drossel) would like to begin by commenting on the use of the terms 'quantum mechanics' and 'reduction' in Halvorson's paper. I want to emphasise that quantum mechanics is not an axiomatic theory from which solid state physics or statistical physics can be derived deductively. As Koons has written above, there is no C algebra for all constituent particles of such a system from which all its properties can be obtained. Rather, quantum mechanics is a toolbox with many different elements, such as unitary time evolution, preparation and measurement events, vacuum states, their quasi-particle excitations and the associated algebra with creation and annihilation operators, pure and mixed density matrices, reversible and irreversible (e.g. the Lindblad equation) time evolution equations. Which tools should you use? That depends on the context. Halvorson's hope that they all can be reduced to a single theory is in my opinion disproven by the way how condensed matter theory and statistical physics are done.

This brings me to my second concern. Halvorson seems to think that we (Ellis and I) *deny* that "larger things are quantum mechanical" (p.11). What does he mean? I do not deny that quantum mechanics can be used to describe finite-temperature systems. Indeed, in the courses I teach on condensed matter theory and statistical physics, I use quantum-mechanical calculations in many places. I do deny that these calculations can be viewed, even in principle, as a *derivation* from the supposedly fundamental many-particle Schrödinger equation for all the atoms of the system, which assumes the unitary time evolution of a wave function for a system of many particles. In other words, I deny that, when I use the Schrödinger equation of a many-particle system and when I use quantum mechanics to model a finite-temperature system, I am applying to both kinds of system a single unified theory. The Nobel laureate Antony Leggett discussed this tendency to conceive condensed matter physics as being merely derivative of particle physics in his paper "On the nature of research in condensed state physics" (Leggett 1992). Our resistance to this kind of physical reductionism is not based upon ignorance (something comparable to a God-of-the-gaps argument, as suggested by Halvorson), but on a deep knowledge of how solid state physics and statistical physics are used *in practice*. When quantum theories are successfully applied to solid state physics and statistical physics, they do not assume the unitary time evolution of a wave function of all the particles of the system. Halvorson writes, “I have yet to see a case of a non-measurement scenario where non-unitary dynamics provide a better description” (p.17). I see them everywhere: the world is full of events, where one of several possible possibilities becomes reality. We wrote about this in our paper on CWC theory (Drossel & Ellis 2018).

And decoherence theory is not a way of resolving this contradiction, as Halvorson seems to suggest (cf. Halvorson, 12): it only explains how the reduced density matrix of a system can become diagonal due to interaction with an environment, but it cannot explain why one observes only one of the possible outcomes of all the time evolutions contained in the density matrix. Claiming that decoherence explains the emergence of classicality means to confound a logical AND (which results from decoherence calculations) with a logical OR (which is what we observe). Furthermore, decoherence calculations – like other derivations done in condensed matter theory and statistical mechanics – are not a logical deduction from a many-particle Schrödinger equation. Instead, all these calculations require auxiliary assumptions such as statistical independence, localization of particles, classicality of certain degrees of freedom, etc. depending on the type of derivation. Ellis and I have commented on decoherence theory and other interpretations of the measurement process in our CWC paper, and I have commented more generally on the derivations done in condensed matter theory and statistical mechanics in more recent papers (Drossel 2020 and 2021). These derivations are a ‘reduction’ or ‘explanation’ in some sense, as they are based on a many-particle quantum mechanical description, but not in the narrow sense of being a mere deduction from a many-particle wave function. Like every theory, they are an idealization with a limited range of validity, applicable on appropriate scales (e.g. length, time, energy) and when external influences can be neglected. Ellis and I have discussed this in our CWC paper, where we specify in detail the different types of mathematical models employed when describing a measurement process starting from the incoming photon to be detected and ending with the deflection of a pointer. The limited validity of theories is essential if the simultaneous action of different causes shall hold. If everything was fully determined by the unitary time evolution of the many-particle wave function, there would be no room for other influences. But if a quantum mechanical description is an approximate description with limited validity and is causally open to the wider context, then explanations in terms of multiple causes are required – causes which are not just semantically different (Halvorson p.7), but ontologically.

In closing this paper, I (Ellis) would like to focus on a couple of remarks made by Koons and Simpson. I wish to suggest some important clarifications. In I. above, Koons states

> Demovorson supposes that the hylomorphist must deny that middle-sized objects are "quantum-mechanical things" at all. He supposes that hylomorphists must say that quantum mechanics has "limited validity," in the sense that middle-sized objects must "violate the laws of quantum mechanics," and that there must be predictions of quantum mechanics that are "wrong."

and then disagrees with that position. But I (Ellis) agree with Demovorson in this respect. Indeed that is the central content of my two papers (Ellis 2023, 2024) where I advocate a local wave function approach to quantum theory.

What I claim in these papers is that it is not true that in general there is a single wavefunction for arbitrary middle-sized objects. Rather, quantum physics applies locally everywhere as described by local wavefunctions. However, except in very carefully contrived circumstances these local wavefunctions do not combine to form a single wave function for an arbitrary object because of the many non-linear effects that occur in real world physics. It is for this reason that middle sized objects are almost always not quantum mechanical things. Nothing in an Aristotelian worldview contradicts this understanding, which assigns macroscopic objects full causal powers as classical objects.

As regards the Schrödinger-cat thought experiment, there simply is no wave function for a cat as a whole (alive or dead), and that entire discussion in any context whatever therefore simply falls away. All this is consistent with Drossel's view that phonons are modeled as pretty well localized (quasi-) particles that interact locally.

In II. above, Simpson raises a worry about CWC for hylomorphists because he suggests the 'classicality' of a physical system is an *extrinsic* feature of the system, inasmuch as this is something it derives from its environment, rather than something it possesses *of its own nature*. In my view, however, the classicality *per se* derives from internal features of the system, namely the limits to unitary dynamics of its interacting components. The paper by Ellis and Drossel states (§3.1),

> […] the photon cannot be absorbed without involving a third partner in the transition. Without this third partner, it is impossible to simultaneously achieve energy and momentum conservation. In our measurement device, this third partner is the crystal lattice of the semiconductor, which can take up the surplus momentum via the motion of ions, i.e. via the phonon heat bath.

Thus that heat bath (let us call it HB1) is *intrinsic* to the detector, and is the local environment for both the ions and the photon. This interaction is a crucial form of downward causation from the level of the crystal lattice to the level of ions and photons (Ellis 2020). However, it is correct to say that HB1 is in contact with the larger heat bath, HB2, because it is the context of the experimental apparatus as a whole, and this is the basis of Simpson's concern. It is via HB2 that the external arrow of time, derived from the Direction of Time generated by the expanding universe, is communicated to the interacting components just mentioned. Nonetheless, I believe that this is all fully compatible with hylomorphism, and gives it a sound basis in relation to quantum theory.

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