

Quantum Mechanics without Ontology?

Configuration Space, the Arena Problem, and the Road Not Taken in 1926

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July 30, 2026

Prepared in cooperation with Claude (Anthropic); the argument and claims are the author's, with the AI assisting in drafting and in surveying the literature.

Abstract

It is often said that quantum mechanics dispenses with ontology and that its predictive success licenses the omission. This paper argues that the situation is both more precise and more serious. First, quantum mechanics does not lack an ontology outright: under the preparation-independence assumption, the Pusey–Barrett–Rudolph (PBR) theorem tells against a purely epistemic reading of the quantum state, so the state is naturally taken to be ontic. The genuine difficulty is not the *existence* of an ontology but its *arena*: the state that PBR renders real is a function on $3N$ -dimensional configuration space, not on the three-dimensional space that observers and instruments occupy. The interpretive troubles of quantum mechanics — the measurement problem, the status of collapse, the profusion of interpretations — are, I argue, symptoms of this arena problem rather than of a bare absence of the real. Second, I revisit the historical moment (spring 1926) at which the wave function was lifted from three-dimensional space to configuration space, and the objections of Schrödinger and Einstein were set aside; I ask why a commitment so basic was relinquished so rapidly. Third, I situate the options in the contemporary debate between *wave-function realism*, which reifies the configuration-space object, and *primitive ontology* approaches, which locate the fundamental beables in three-dimensional space, and I present a recent three-dimensional charge-density formulation (RealQM) as one under-explored member of the latter family — a concrete realization of the road not taken. Finally, I use the case of quantum computing to illustrate a practical corollary: technological programs can inherit the arena problem, staking resources on the physical reality of the exponentially large amplitude, and the ontological status of that amplitude is therefore not an idle question.

1 Introduction

A familiar defense of standard quantum mechanics holds that although the theory declines to say what is physically real between measurements, its unrivaled record in predicting measurement statistics renders the omission harmless. Two things are run together in this defense that ought to be kept apart: whether quantum mechanics has an ontology at all, and, if it has one, whether that ontology is located where physics has always located its subject matter — in three-dimensional space. I shall argue that recent results and debates let us be precise here. The quantum state is not plausibly a mere summary of an agent's knowledge (§2); but the state it is natural to reify lives

on configuration space, and it is this displacement of the fundamental object from three-space to a high-dimensional arena — not a bare absence of ontology — that generates the theory’s foundational difficulties (§3). Read this way, the century-old interpretive impasse is an *arena problem*, and the space of responses is exactly the contemporary contest between wave-function realism and primitive ontology (§4). I recall the historical juncture at which the arena was chosen (§5), present a three-dimensional charge-density formulation as an under-explored primitive ontology (§6), and close with a practical corollary drawn from quantum computing (§7).

2 Ontology versus epistemology, and what PBR settles

Two questions must be separated: *ontology*, what exists; and *epistemology*, what and how we may know of it. On the epistemic reading associated with parts of the Copenhagen tradition, the quantum state represents knowledge or information about outcomes rather than a physical property of an individual system. Harrigan and Spekkens [1] made this reading precise within an ontological-models framework, distinguishing ψ -epistemic from ψ -ontic models. The Pusey–Barrett–Rudolph theorem [2] then showed that, under a preparation-independence assumption, ψ -epistemic models of the relevant kind cannot reproduce the quantum predictions: distinct pure states cannot both correspond to the same underlying physical state. The natural moral, widely (if not universally) drawn, is that the quantum state is *ontic* — a physical feature of the system, not merely a catalogue of expectations.

This matters for the present argument in a specific way. It means that the slogan “quantum mechanics has no ontology” is, taken literally, too strong: there is a real state, and it is the wave function. But PBR fixes only *that* the state is real, not *where* it is real. The state it certifies as physical is $\Psi(\mathbf{x}_1, \dots, \mathbf{x}_N)$, a field on $3N$ -dimensional configuration space. The question that remains — and that PBR does not touch — is whether an ontology carried by an object on configuration space can serve the explanatory role physics has always demanded of its ontologies, which have without exception been ontologies in three-dimensional space or four-dimensional spacetime. I turn to that question now.

3 The arena problem

Every physical theory before quantum mechanics answered, first, the question of what exists, and located the answer in ordinary space: masses at positions, fields on $\mathbb{R}^3$, molecules, a spacetime metric. The predictive content followed as the computed behaviour of those spatially located things. The distinctive feature of quantum mechanics is that its fundamental object is a function not on physical space but on a space whose dimension grows with particle number. Kohn [3] put the working consequence bluntly in his Nobel lecture: the many-electron wave function is not, for large N , a legitimate computational object, being unrecordable even in principle beyond a modest number of particles. Whatever its ontic status, an object we cannot in principle record and which does not inhabit the space of laboratories and observers sits awkwardly as the bearer of physical reality.

The interpretive pathologies of quantum mechanics can be read as consequences of this displacement. The *measurement problem* arises because the link between the configuration-space state and definite three-dimensional facts (pointer positions, tracks, clicks) is not supplied by the unitary dynamics and must be added by hand, as collapse; the *Heisenberg cut* is the unlocatable seam be-

tween the configuration-space description and the three-dimensional description we actually read; the nonlocality that so troubled Einstein [4] is the difficulty of a correlated whole that has, in three-space, no separated parts to be local to. On this diagnosis the trouble is not that there is nothing real, but that the something real is in the wrong arena, and the recovery of ordinary three-dimensional facts from it is left unaccounted for.

4 Wave-function realism and primitive ontology

The contemporary metaphysics of quantum mechanics is, in effect, an argument over the arena. *Wave-function realism* accepts the configuration-space object as fundamental and takes the high-dimensional space to be the real arena of the world, our three-dimensional experience being derivative [8, 9, 10, 11]. The program is serious and has able defenders, but it purchases realism at the price of demoting three-dimensional space to appearance and owes an account — the “arena” or “3D-emergence” problem — of how the manifest spatial world is recovered. *Primitive-ontology* approaches take the opposite route: they posit fundamental beables in three-dimensional space or spacetime — particles, a matter-density field, or flash events — and assign the wave function a nomological or guiding role rather than the role of the primary substance [12, 13, 14, 15]. On these views the wave function may still be ontic in PBR’s sense while not being the *primitive* ontology; what is fundamentally real is in three dimensions.

The choice between these families is not decided by PBR, which speaks only to the reality of the state, not to its arena. It is decided, if at all, by which program better discharges the explanatory duties of a physical theory: recovering the three-dimensional phenomena, dissolving the measurement problem, and doing so without ad hoc additions. It is against this backdrop that the historical contingency of the standard choice, and the availability of three-dimensional alternatives, become salient.

5 The choice of 1926

The arena was chosen quickly. In the first months of 1926 Schrödinger’s wave mechanics represented the one-electron atom by a field $\psi(\mathbf{x})$ on ordinary space, and Schrödinger initially hoped to read $|\psi|^2$ as a charge density there. The extension to N interacting electrons required a single function $\Psi(\mathbf{x}_1, \dots, \mathbf{x}_N)$ on configuration space; Born’s statistical interpretation [5] then read $|\Psi|^2$ as a probability over configurations. Schrödinger, in his correspondence with Lorentz [6], and Einstein, through the Solvay debates and later the EPR argument [4], both objected that a theory whose fundamental object was a many-dimensional amplitude had relinquished a physical picture in three-space; both were overruled as the Göttingen–Copenhagen synthesis consolidated [7]. That the arena was fixed so rapidly, and the dissent of the theory’s own principal architects set aside, is historically striking and, I suggest, philosophically relevant: it shows the configuration-space choice to have been a contingent turn rather than a forced one, taken under the pressure of immediate predictive success and a positivist climate that treated the demand for an ontology as metaphysics in the pejorative sense.

6 A three-dimensional charge-density formulation

That a three-dimensional alternative was available, and not merely desired, can be shown constructively. One may represent the N electrons of an atom or molecule not by a single amplitude on $3N$ -space but by N non-negative charge densities on ordinary space, supported on disjoint regions, and take the ground state to minimize the ordinary Coulomb energy over these densities and their spatial partition; excited and time-dependent behaviour follow by admitting complex phases. This “RealQM” construction [17] is a member of the primitive-ontology family in the specific sense that its beables — charge densities — are fields in three-dimensional space, and it is offered here not as an established replacement for standard quantum mechanics but as an existence proof: a concrete, computable, three-dimensional ontology in the spirit Schrödinger first sought. Two clarifications place it correctly in the debate. It is not a hidden-variable theory: it adds no parameters beneath the amplitude (as de Broglie–Bohm does) but replaces the amplitude, as primary object, with charge in three-space. And it is compatible with PBR’s ontic conclusion while declining wave-function realism’s arena: the real thing is a state, but a state of charge in three dimensions rather than a field on configuration space. Its empirical reach and its open problems — notably a full account of spin exchange and of the statistics of measurements on entangled systems — are documented elsewhere [17]; the philosophical point here is only that the primitive-ontology-in-3D option is live and was the road not taken.

7 A practical corollary: quantum computing

The arena problem is not purely interpretive; a technological program can inherit it. The claimed advantage of quantum computation rests on treating the joint state of n qubits — an amplitude in a 2^n -dimensional Hilbert space — as a physical resource on which operations act “in parallel.” This is the configuration-space object again, and whether the exponential advantage is physically real depends on whether that object is a physical resource or a formal device for the statistics of a system that is, in three-space, of modest size. The two horns of §4 bear directly on the technology: on wave-function realism the exponential resource is real and (decoherence permitting) exploitable; on a three-dimensional primitive ontology there is no exponential thing in the device, and the scalable advantage lacks a substrate. I do not claim the matter is settled — small-scale devices demonstrably perform entangling operations and sampling tasks, and the scalable, fault-tolerant regime is where the question lies. It is worth noting that skepticism about that regime is not confined to ontological considerations: Kalai [16], among others, argues on the basis of noise that fault-tolerant quantum computation may face an in-principle barrier. The philosophical observation is narrower and, I think, secure: the feasibility of scalable quantum computing is entangled with the ontological status of the configuration-space state, so the question of arena that PBR leaves open is not academic but bears on where a great deal of scientific effort is being directed.

8 Conclusion

The claim that quantum mechanics abandons ontology should be replaced by a sharper one. The quantum state is plausibly real (PBR); the difficulty is that it is real on configuration space, and the recovery of the three-dimensional world from it is exactly what the theory does not supply — the arena problem, of which the measurement problem and its relatives are symptoms. The

contemporary options are wave-function realism, which keeps the arena and demotes three-space, and primitive ontology, which keeps three-space and demotes the wave function to a non-primary role. The historical record shows the configuration-space arena to have been a rapid and contested choice, not a necessity, and a constructive three-dimensional charge-density formulation shows a primitive-ontology alternative to be available in fact and not only in aspiration. Whether one adopts it or not, the lesson is that “where is the quantum state real?” is a substantive question with consequences reaching from the measurement problem to the prospects of quantum technology, and that it was closed too early, too confidently, in 1926.

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