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Quantum Theory and Novel Scientific Language: Defending a Pragmatist View

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Abstract

This paper advocates for a pragmatist view on quantum theory, offering a response to David Wallace's recent criticisms of Richard Healey's quantum pragmatism. In particular, I challenge Wallace's general claim that quantum pragmatists—and anti-representationalists more broadly—lack the resources to make sense of the novel 'quantum' language used throughout modern physics in applications of quantum theory. I conclude by posing a challenge to quantum representationalists.

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1. Introduction

Quantum pragmatists—and related perspectives—view quantum theory as prescriptive rather than descriptive (Healey 2012a, 2012b, 2017b, 2020, 2022; Friederich 2011, 2015; Fuchs and Stacey 2019). For pragmatists, quantum theory is primarily seen as a tool that guides users in determining how strongly to affirm empirically significant magnitude claims about physical systems of interest. In this framework, only the magnitude claims describe the system, while quantum theory plays a purely prescriptive role, advising on the significance and credibility of those claims. As Richard Healey (2017b) explains in his recent book, quantum theory is revolutionary because it helps us better represent nature through this advisory role—without directly representing nature itself.[1]

This paper defends quantum pragmatism by responding to David Wallace's (2020a, 2020b) recent criticisms of Healey's (2017b) pragmatist view. Wallace argues that attributing representational content to quantum theory is necessary to account for its broad range of applications in modern physics, including both non-relativistic quantum mechanics and relativistic quantum field theories, such as the gauge theories underlying the Standard Model. While Wallace acknowledges that anti-representationalist views can account for the predictive success of quantum theory in non-relativistic quantum mechanics, he contends that even in this context, pragmatists struggle to make sense of certain 'quantum' language used to describe physical phenomena and, allegedly, even to define physical systems. Beyond non-relativistic quantum mechanics, Wallace further argues that anti-representationalist views fall short of accounting for the full empirical success of quantum theory, particularly due to their inability to make sense of the novel 'quantum' language introduced during the theory's development.

Overall, Wallace's criticisms are far-reaching, but I do not believe they succeed. In this paper, I challenge Wallace's general claim that quantum pragmatists—and anti-representationalists more broadly—lack the resources to make sense of the novel 'quantum' language used throughout modern physics. Specifically, I propose and defend a pragmatist strategy for introducing and understanding this novel language (Section 3), after first outlining

[1] The contrast here lies with classical physical theories, which aim to represent nature directly.

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Healey's (2017b) pragmatist view of quantum theory, which Wallace's criticism targets (Section 2). Finally, in Section 4, I pose a challenge to quantum representationalists and offer concluding remarks.

2. Healey's Pragmatist Interpretation of Quantum Theory

Philosophical pragmatists, in general, are committed to the claim that the use of linguistic expressions determines their content. Consider the sentence, 'Stealing is wrong.' At first glance, this sentence might appear to attribute a property—*wrongness*—to the action of stealing. However, adopting this view leads to metaphysical questions about the nature of this property (if such there be), including where in the world to 'place' it. Expressivism, as a form of pragmatism, dissolves this perplexing 'placement problem' by focusing on how the sentence is actually used: namely, to express a language user's *attitude* toward stealing. Thus, the function of the sentence is not descriptive, but *expressive* (Price 2011, 7-9).

Healey adopts a similar strategy in the quantum context. According to Healey, by examining how claims about quantum states of physical systems are actually used, we see that they are not employed to describe or represent, but rather to infer Born probabilities in legitimate applications of the Born rule. Much like the 'Stealing is wrong' example, Born probabilities are not used to describe any element of physical reality. Instead, they guide an agent who accepts quantum theory in forming partial beliefs about statements that express *canonical magnitude claims* (CMCs). These 'non-quantum' claims take the following form: 'The value of dynamical variable M on physical system s lies in set Δ (of real numbers)', abbreviated as $M_s \in \Delta$ (Healey 2017b, 80).

Healey distinguishes *quantum* claims from *non-quantum* claims, where the former are claims about quantum states, Born probabilities, self-adjoint operators, or other novel elements of quantum theory. Quantum claims are not used to *describe*, but to *prescribe*. Healey argues that no quantum claim describes anything in nature. His pragmatism can be distinguished from others (e.g., Rorty 1979, 1982; Price 2011, 2013) in that he is not a *global* anti-representationalist. Accordingly, certain other (non-quantum) claims can be understood descriptively without contradicting Healey's account, provided they are not claims about quantum states, Born probabilities, and so on.

Healey, in Bohrian fashion, maintains a quantum-classical dichotomy, according to which only the classical domain has representational content. In applying quantum theory, all descriptive content is found in the CMCs associated with the physical system of interest. These descriptive magnitude claims are formed prior to applying quantum theory, which then advises its users on which cognitive attitudes are appropriate to adopt regarding these magnitude claims.

Consider the example of a particle confined to some region R, such as an electron in a box, with wave-function $\psi(\vec{x}, t)$. The role of quantum theory, according to Healey, is not to describe the particle's location but to provide authoritative advice to the user of quantum theory regarding magnitude claims (specifically, CMCs). In this example, the CMCs take the form: 'the electron is in region $r \subset R$', where r is some subregion of R (or possibly R itself). Different choices of r correspond to different CMCs.

Applications of the Born rule provide expert advice to a user of quantum theory about how to apportion credence across the allowed values of a physical quantity of interest—at least when sufficient environment-induced decoherence has occurred (see Healey 2020, 131). In the example of an electron in a box, the degree of confidence an agent should have that the electron is in a region $r \subset R$ is given by:

$$\int_{region\, r} |\psi(\vec{x}, t)|^2 d^3x \, .$$

Though the distinctive feature of Healey's (2017b) approach is his reading of the quantum state as providing *advice,* what makes it most controversial is its non-representational view of the quantum state—a position it shares with various epistemic approaches, such as Simon Friederich's (2011, 2015) and Christopher Fuchs' (2002).

3. Quantum Pragmatism and Novel Scientific Language

To be a viable interpretation of quantum theory, an interpretation must be able to make sense of the novel language introduced into physics alongside the development of quantum theory, particularly those concepts that are inextricably tied to its empirical success. If an interpretation fails to account for the novel terms introduced during the development of quantum theory, it cannot make sense of claims and predictions that physicists make involving these terms. But if an interpretation cannot account for at least the predictive success of a theory, then it should not be considered a viable interpretation of that theory.

Healey agrees that a successful interpretation of quantum theory needs to account for the introduction of novel scientific language. For instance, he states:

> A successful interpretation must explain how quantum mechanics may be formulated as a precise physical theory and unambiguously applied to real-life physical situations . . . by applying quantum mechanics we become able better [sic] to describe and represent those situations in non-quantum terms. I say 'non-quantum' rather than 'classical' to acknowledge that the progress of science naturally introduces novel language to describe or represent the world. (2017a)

However, as Wallace (2020a, 89) notes, it is completely unclear how, on *Healey's* account, we can understand science 'naturally introducing' this novel language. He writes: 'The language of experimental physics is rich with terms—'laser', 'superconductor', 'LCD', whose very *definition* is quantum-mechanical' (ibid., 89; my italics).

Healey does not spell out how a pragmatist can make sense of such novel language and phenomena. However, I believe the following provides a viable pragmatist response to how we can understand the introduction of certain novel terms. Consider the term 'superconductor'. This term refers to a material in which the phenomenon of superconductivity—characterized by current flow with zero resistance and the exclusion of magnetic fields from the interior of the material (the Meissner Effect)—occurs. It is not the case that quantum theory (construed representationally) is needed to know or learn about this *experimentally* observable phenomena: by continually decreasing a metal such as lead's temperature while measuring its resistance and magnetic field strength, it can be observed that, below a certain critical temperature, both resistance and magnetic field strength inside the material vanish. Therefore, we do not need quantum theory to account for the introduction of terms like 'superconductor' or 'superconductivity'. All of the quantities involved in this explanation—temperature, current, resistance, and magnetic field strength—have a classical basis.

In general, a pragmatist would understand *all* novel scientific language as either introduced on the basis of experimentation or 'read off' from classical theories of physics—i.e., theories whose models do not include specifically quantum objects such as wave-functions, state vectors, and self-adjoint operators. More precisely, we can distinguish five sources of novel entities and magnitudes, but only three of these can be legitimately appealed to by a pragmatist when introducing new scientific language:

S1. Observation/experiment—unmediated by physical theory.

S2. Observation/experiment—mediated by classical theories *only*.

S3. Observation/experiment—mediated by physical theories, *including* quantum theories.

S4. Classical theories—from which entities and magnitudes that are represented and understood as beables might be 'read off'.

S5. Quantum theories—from which entities and magnitudes that are represented and understood as beables might be 'read off'.

Non-controversially, pragmatists have access to sources S1, S2, and S4. Given the defining commitments of quantum pragmatism, however, S5 is not available to pragmatists: novel entities and properties cannot be 'read off' from a (non-representational) pragmatic tool. Novel entities and magnitudes might only be read off from theories that are understood as describing or representing physical systems in the world. Additionally, pragmatists also cannot appeal to S3 in the sense of appealing to quantum theory as a *reason* for interpreting experimental data in a certain way, e.g., as evidence for a certain quantum beable. A pragmatist can only understand language (as legitimately) introduced into science, if its introduction does not rely on understanding quantum theory representationally.

3.1. Making Sense of Novel Scientific Language as a Pragmatist

In this section, I argue that quantum pragmatism delivers the goods. Specifically, I demonstrate that it can introduce and make sense of novel 'quantum' language—language that Wallace contends Healey's view cannot accommodate. I focus in particular on Wallace's (2020b) criticism that Healey's interpretation lacks the resources to account for the gauge theories underlying the Standard Model (SM) of particle physics. Wallace writes:

> [Healey's] account seems to have to eschew most of the talk of unobservables that usually happens in physics, and this seems to make his position more radical than he recognises. He says, for instance, (p.205, fn.3) that '[t]he Standard Model has certainly enabled us to make claims about magnitudes (strangeness and color) and entities (the top quark and the Higgs boson)'. But I don't see how, on Healey's account, it *has* enabled us so to do. These magnitudes are not remotely classical; nor are they in any way picked out by decoherence (which operates at much lower energy scales). (2020b, 386)

Thus, Wallace is questioning whether Healey's (anti-representationalist) interpretation can even make sense of certain magnitudes and entities commonly associated with the quantum gauge theories of the Standard Model.

One way to be 'alerted' about the possible existence of an an entity or magnitude is through understanding physical theories representationally—as *quantifying* over entities or properties, and then reading these off from theories' equations in interpreting them. But if one denies that a certain theory is descriptive, as proponents of quantum pragmatism do with quantum theory, then this source—S5—is unavailable. That is, a pragmatist cannot understand quantum theory as 'alerting us' to any entities or properties in this representationalist way.

But, recall, quantum pragmatism is only committed to a non-descriptive reading of *quantum* theories, not *all* physical theories. Since one can formulate classical (i.e., non-quantum) versions of all the gauge theories underlying the SM, I propose pragmatists adopt the strategy of appealing to *these* theories to make sense of (gain acquaintance with, comprehend) key concepts that are commonly associated with the *quantum* gauge theories of the SM.

Color charge, for instance, can be modeled by *classical* chromodynamics in addition to quantum chromodynamics, and the former has been extensively studied from both physics and philosophical perspectives.[2] It is from the classical version of chromodynamics that, e.g., Maudlin (2007, chapter 3) and Gilton (2021) extract tentative metaphysical conclusions about color charge. Maudlin, specifically, appeals to the fiber bundle formulation of classical chromodynamics. After introducing this formalism, Maudlin argues that it suggests a metaphysical picture which is in tension with traditional views relying on universals, tropes, or natural sets.

I mention Maudlin's argument not to defend or dispute it, but to highlight his appeal to *classical* chromodynamics—specifically its geometric formulation using the fiber bundle formalism. Maudlin is not alone in drawing metaphysical insights from classical gauge theories. Gilton (2021), for example, also takes classical chromodynamics seriously, although she disputes some of Maudlin's conclusions. According to Gilton, the $SU(3)$ group structure of chromodynamics, manifest in the fiber bundle formulation, suggests that color charge should be understood on three different levels. Gilton contends that Maudlin's argument only applies to one of these levels. The full details of Gilton's argument need not concern us here (though

[2] For a physics perspective, see, e.g., Kosyakov (2007), and references therein. For a philosophical perspective, see, e.g., Gilton (2021) and Maudlin (2007).

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interested readers are encouraged to consult Gilton 2021 and Maudlin 2007, Chapter 3 for further elaboration). Nevertheless, her debate with Maudlin provides an excellent example of philosophers of physics engaging with *classical* gauge theories.

Furthermore, Gilton and Maudlin are not alone in making this methodological choice. Brading and Brown (2004) also engage with the interpretation of classical gauge theories, particularly with respect to whether gauge symmetries are observable. Greaves and Wallace (2014) address the same question but dispute Brading and Brown's conclusions. Additionally, Healey (2007), ten years prior to publishing *The Quantum Revolution in Philosophy*—the book in which he fully articulates and defends his pragmatist interpretation—engaged with classical gauge theories and philosophical questions regarding how they should be interpreted and formulated. Belot (1998), Earman (2003), and Rosenstock and Weatherall (2016) represent further examples of philosophical engagement with classical gauge theories. While this list is not exhaustive, it serves to establish that there is a well-established precedent in the philosophical literature for drawing on both quantum gauge theories and their corresponding classical formulations.

Quantum pragmatists should follow and build upon this precedent. It turns out that for each of the quantum gauge theories of the SM, there are *classical* counterparts (Maxwellian electromagnetism as well as classical Yang-Mills-Wong theories of the strong and weak interactions) (Kosyakov 2007). Pragmatists can appeal to the classical gauge theories as 'alerting' us to the possible existence of various entities and properties that are commonly associated with the quantum gauge theories of the SM. Their empirical *in*adequacy notwithstanding, the classical gauge theories of the SM nevertheless serve as a resource from which pragmatists can gain acquaintance with various magnitudes and entities—such as color charge, strangeness, and the Higgs field—that Wallace argues quantum pragmatism cannot make sense of. From the pragmatist perspective I am recommending, it does not matter that the classical gauge theories do not enjoy the same empirical success as their quantum counterparts: it is quantum theories—*not* classical theories—that are used to make predictions about the non-quantum ontology we have acquaintance with from classical theoretical physics and experiment.

The way in which pragmatists can appeal to classical gauge theories to account for the SM is analogous to the way they appeal to Newtonian mechanics to account for non-relativistic quantum mechanics. Even in the non-relativistic case, a pragmatist does not understand quantum theory as representing the relevant dynamical variables (energy, position, linear momentum, and angular momentum), because those variables are not a part of quantum theory (only self-adjoint operators and other mathematical objects like wave-functions are) even though quantum theory is used to provide advice about magnitude claims featuring them. We are acquainted with these dynamical variables from Newtonian mechanics and experimental physics. These variables enter into, and are represented by, CMCs. Forming CMCs occurs before deploying the quantum advice-generating recipe. In forming CMCs, one can use the following ingredients: (1) terms from natural language, (2) concepts from classical physics, and (3) terms/concepts introduced on the basis of experiment. The appeal to classical physics in forming CMCs—whether it be Newtonian mechanics or classical gauge theories—precedes the deployment of quantum theory. The descriptive content from classical physics is embedded in the CMCs, and quantum theory then provides authoritative advice about them. Therefore, the magnitudes of SM gauge theories (for example) are not any more problematic for the pragmatist to make sense of than the standard dynamical variables of classical particle mechanics, such as energy, position, and momentum. Wallace himself concedes that these classical variables are comprehensible to the pragmatist, who understands classical physics representationally and can thus straightforwardly 'read them off' from Newtonian mechanics as ontological posits (S4).

Accepting the strategy of appealing to the classical versions of SM theories—to gain acquaintance with novel 'quantum' terms—is entirely compatible with quantum pragmatism, which views the quantum gauge theories of the SM as anti-representational and, therefore, as lacking any ontology of their own. Classical gauge theories, understood representationally, inform pragmatists about the possible existence of novel entities and properties unknown to Newtonian physics. Quantum theories are still understood as merely providing expert advice to users of quantum theory about *non-quantum* ontology.

Healey did not have the proposed strategy in mind, since he wrote that 'The Standard Model has ... enabled us to make claims about magnitudes (strangeness and color) and entities (the top quark and the Higgs field) *unkown* [sic] *to classical physics*' (Healey 2017b, 205, fn. 3; my italics). Yet, appealing to classical gauge theories is, ipso facto, appealing to 'classical' physics, at least in one sense of 'classical' (and the one I intend). I am understanding 'classical physics' as including all theories of classical mechanics (not just 'point-particle classical mechanics') (see Wallace 2018, section 3), classical electrodynamics, Newtonian gravity,

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general relativity, and the classical versions of the gauge theories comprising the SM. None of these examples that I have in mind when I use the term ‘classical physics’ have undergone the canonical (or another) quantization procedure, and so might reasonably be grouped together as ‘classical’ theories. Indeed, this distinction would seem to capture a standard practice in theoretical physics, wherein (in many cases) physicists arrive at the quantum versions of theories by starting with the corresponding classical theory and quantizing it. This practice is exemplified by one of the main research programs currently working on quantum gravity, namely the camp which began from Einsteinian relativity and aims to quantize the general theory.

If the strategy I have suggested is viable, pragmatists adopting it should not understand magnitudes such as strangeness and color as unknown to classical physics, since classical gauge theories do quantify over these properties. Consider the property of color. In classical chromodynamics, color charge can be treated using the representation theory of the Lie group *SU* (3) (Gilton 2021, 633-35). The two fundamental representations of *SU* (3) are three-dimensional, and a set of basis vectors for the carrier spaces of these representations are used to represent the ways quarks and anti-quarks can possess color charge. By convention, the first fundamental representation of *SU* (3), whose carrier space is $\mathbb{C}^3$, is used for quarks. Following Gilton (2021, 634-35), one can write a set of basis vectors as

$$r = \begin{pmatrix}1\\0\\0\end{pmatrix}, b = \begin{pmatrix}0\\1\\0\end{pmatrix}, g = \begin{pmatrix}0\\0\\1\end{pmatrix},$$

where the labels r, b, g, (red, blue, green) stand for the three different ways quarks can possess color charge. Mutatis mutandis for anti-quarks. For these, the second fundamental representation of *SU* (3), which is dual to the quark color space, is used:

$$\bar{r} = \begin{pmatrix}1\\0\\0\end{pmatrix}, \bar{b} = \begin{pmatrix}0\\1\\0\end{pmatrix}, \bar{g} = \begin{pmatrix}0\\0\\1\end{pmatrix}.$$

Here, the labels $\bar{r}$, $\bar{b}$, $\bar{g}$, stand for anti-red, anti-blue, and anti-green, respectively. These orthogonal vectors in the *SU* (3) anti-color space represent the three ways anti-quarks can possess color charge in classical chromodynamics (ibid., 634-35). Based on acquaintance with this theory, a pragmatist can comprehend claims about color charge that physicists working on quantum chromodynamics often make (e.g., that it is a property which certain subatomic particles possess, or that it comes in three ‘colors’).

In understanding magnitudes and entities through classical theories, a pragmatist can then meaningfully include these ingredients in CMCs, about which quantum theory often generates advice.[3] Pragmatists can implement this strategy because they understand classical theories representationally—that is, as intending to describe physical reality. Although quantum theories are not understood representationally, pragmatists can still make sense of claims about various magnitudes and entities commonly associated with them by appealing to the classical counterparts of these quantum theories.

Consider quantum fields as another example. Pragmatists can gain acquaintance with quantum fields through their classical counterparts, allowing them to meaningfully comprehend claims and discussions concerning quantum fields based on their understanding of classical field theory. On this view, quantum fields are just classical fields, subjected to different field equations and now quantization constraints. However, quantization is not viewed as altering the physical nature of the field (if such a thing exists). For instance, one might understand the Higgs field as a classical field, with 'quantization' being a mere mathematical process useful for deriving a more effective tool for prediction or advice-generation. (Alternatively, a pragmatist might regard quantum fields wholly *instrumentally*—i.e., as part of a mathematical framework for generating advice, with no ontological commitments attached.) This same perspective applies to quarks, muons, and other Dirac fermions, which can be described classically by spinor fields on spacetime. As with the Higgs field, quantum pragmatists might understand these spinor fields as classical fields that can be quantized using the canonical quantization method or another procedure. However, a pragmatist would view such processes as mere mathematical recipes—tools for arriving at more effective instruments for prediction about *non-quantum* ontology, i.e., ontology that can be introduced and understood through S1-, S2-, or S4-based introduction stories.

So far, I have argued in this section that pragmatism can account for certain properties and entities that critics like Wallace claim it cannot—specifically by appealing to the classical

[3] I say 'often', since quantum theory does not provide advice about all possible magnitude claims representing dynamical variables (e.g., it cannot be used to provide advice about magnitude claims representing the classical property 'entropy').

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versions of the fundamental theories underlying the SM. This strategy of appealing to classical theories (S4) is complementary to appealing to observation and experiment (S1, S2), which pragmatists can also utilize as sources for introducing various entities and properties that physicists commonly discuss. I conclude this section by presenting an experiment-based introduction story for the property ‘strangeness’.

Just as with the earlier example of superconductivity, an appeal to experiment seems to work for the property ‘strangeness’, which physicists proposed to explain the unexpectedly long mean lifetime of a particular particle. This new quantum number was introduced based on experimental measurements of the decay rate of the lambda particle (Λ^0). In 1947, based on the prevailing physical knowledge, physicists studying cosmic ray interactions anticipated that this product of proton collisions with nuclei would decay in approximately 10^{-23} seconds. However, experimental results showed a decay time closer to 10^{-10} seconds. The property responsible for the Λ^0 particle’s unexpectedly long lifetime was dubbed ‘strangeness’ (Dorman, 1990).

These cosmic ray experiments and their interpretation described above did not rely on reading quantum theory representationally, i.e., as representing the lambda particle and the property strangeness. Indeed, before these experiments, ‘strangeness’ was not a known property; it was introduced *because* of these experiments—not from ‘reading it off’ quantum theory as a novel ontological posit (S5). Therefore, pragmatists need not become representationalists about quantum theory in order to make sense of or gain acquaintance with the property ‘strangeness’.

4. Concluding Remarks

I have argued that quantum pragmatism can account for the novel scientific language introduced into physics during the development of quantum theory by appealing to classical physics (S4) and the experimental tradition (S1, S2). These sources enable pragmatists to become acquainted with the new entities and magnitudes that physicists began discussing after the advent of quantum theory. Although this might seem to suggest that such novel language must be introduced by ‘reading it off’ quantum theory, I have demonstrated that this is not the case.

Why assume that appealing to classical physics and experiments—understood in ‘non-quantum’ terms—covers all possible examples of entities, properties, or phenomena that a representationalist might claim pragmatists cannot account for? Essentially, quantum phenomena (if such phenomena exist) would require an S3 or S5 introduction-story, but pragmatism does not have access to these sources. While I do not believe there are any distinctively quantum

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phenomena that necessitate reading quantum theory representationally to produce an introduction story, I conclude by posing a challenge to my representationalist critics: namely, to identify an entity, magnitude, process, or phenomenon that (i) is widely accepted by the physics community as physically real and (ii) cannot be accounted for through an S1-, S2-, or S4-based introduction story. If such a phenomenon exists, it might plausibly be said to falsify quantum pragmatism.

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