Book Review: French, S., & Saatsi, J. (Eds.). (2020). *Scientific Realism and the Quantum*. Oxford University Press[*]

David Glick

Department of Philosophy
University of California, Davis
daglick@ucdavis.edu

Quantum mechanics (QM) has long been thought to challenge scientific realism. The Copenhagen school maintained that QM was unable to provide the realist's sought after description of microscopic reality. Today, many believe such a description can be found, but new challenges have arisen. This impressive collection of essays seeks to explore several such challenges. The contributions cover a range of different issues and viewpoints bearing on the broad topic of realism and QM. In this review, I'll touch on three main themes.

1 Underdetermination

There are three mainstream realist approaches to the measurement problem: hidden variables (Bohmian mechanics), spontaneous collapse (the GRW theory), and many worlds (the Everett interpretation). Within the realm of current experimental access, each approach is empirically adequate, but they differ considerably in what they take the world to be like. Prima facie, this is a textbook case of underdetermination: different theories, each equally supported by the empirical evidence but mutually inconsistent. Left unresolved, the realist's inference from empirical success to a description of reality is undermined. *Which* description of reality? What are things *really* like such that QM works as well as it does?

This underdetermination is problematic because of the realist's ambition to take QM as an approximately true description of reality. However, if one drops or weakens this aim, perhaps realism can be rendered compatible with the current plurality of interpretations. Broadly speaking, this is the approach of Carl Hoefer (ch.2) and Juha Saatsi (ch.3). Both authors accept that underdetermination prevents the realist from endorsing the approximate truth of any given

---

[*] Submitted version, Forthcoming in *Journal for General Philosophy of Science*

interpretation of QM. On Hoefer's Tautological Scientific Realism, we ought to only believe in "those parts of contemporary science that can no longer be reasonably doubted" (p.24) and any particular interpretation can certainly be doubted—one of its rivals could be true. Similarly, Saatsi's Progress Realism eschews the "deep metaphysics" about which interpretations differ. By weakening realist commitment in this way, these approaches preserve realism about other areas of science in the face of quantum underdetermination.

But such a resolution comes at a cost. Central to many realists about QM is a need to provide explanations of certain phenomena. For instance, the stability of a hydrogen atom is only adequately explained by appeal to QM. The explanans of such an explanation will involve details about how the ground state is to be understood, which will be interpretation dependent, and hence, off limits for these version of realism. One might hope for a core of quantum claims that are neither reasonably dubitable nor "deep metaphysics," but as Craig Callender highlights (ch.4), interpretations differ significantly even about matters close the empirical periphery of QM. Moreover, even if one is happy to forgo quantum explanations until such a time that the underdetermination is resolved, it's not clear that other areas of science are immune from the quantum blight. Is it really possible to understand things like "the existence and many basic properties of the atoms of the periodic table" (Hoefer, p.25) without appeal to QM? If not, then the explanations provided by the basic properties of atoms lose much of their appeal.

There's a simpler way of resolving underdetermination that doesn't require sacrificing QM's explanatory power. If there's a single *correct* interpretation of QM, then the underdetermination is only apparent. A simple naturalism might recommend looking to scientific practice to determine the content of QM. This might resolve the underdetermination, but potentially at the cost of blocking reflection on the best way to understand QM. However, as J.E. Wolff (ch.6) argues, one can also view the different interpretations as rival scientific theories which can be assessed in terms of their theoretical virtues. Then, the realist might hope that one theory emerges as best and thereby worthy of realist commitment.

David Wallace (ch.5) argues for this conclusion regarding the Everett interpretation. His argument begins with the claim that QM is a *framework theory*: like classical mechanics, QM is an abstract formalism which can be applied to a variety of different concrete situations. Ordinary non-relativistic QM is one of a number of instances of the quantum framework, quantum field theory (QFT) is another. However, interpretations such as Bohmian mechanics and the GRW theory focus on non-relativistic QM, which they treat as a fundamental theory of physics despite its well-known limitations. This leaves Everett as the only viable interpretation of QM qua framework theory. Of course, Wallace is a long-standing advocate of the Everett interpretation and defenders of rival interpretations would object to this characterization. As Callender notes, "the very features that allow the Everettian interpretation its easy extension to new physics are precisely the same features that invite its problems and whose solutions by other programs lead to their explanatory virtues" (p.74).

Indeed, even if rivals have yet to be applied to fully-fledged relativistic QFT, the measurement problem still demands a solution in that context, and these interpretations may be seen as competing research programs to do just that. So, even if we grant Wallace's claim that there isn't underdetermination in the extant approaches to QM, the threat of underdetermination remains in the possibility that one of these approaches may succeed in developing a rival account of QFT. A notable form of underdetermination is the problem of unconceived alternatives [Stanford, 2006], but the situation here is one of merely underdeveloped alternatives. The only way to rule out this possibility is to argue that such constructions are impossible *in principle*, which Wallace hasn't done.

There are other forms of quantum underdetermination beyond that generated by the presence of multiple realist solutions to the measurement problem. Alisa Bokulich (ch.10) and Valia Allori (ch.11) each challenge the central role of the wavefunction in interpretations of QM. Bokulich discusses an alternative quantum formalism: Peter Holland's Lagrangian Quantum Hydrodynamics which represents quantum systems in terms of (parcels of) a continuous fluid [Holland, 2005]. Allori discusses her Primitive Ontology approach according to which the fundamental ontology of QM comprises matter in spacetime. Both authors question the role of the wavefunction in QM in different ways. On Bokulich's view, the presence of an alternative formalism that doesn't feature the wavefunction shows that we shouldn't take it to be representative of a novel piece of physical ontology as proposed by Wavefunction Realists. Allori argues that on her Primitive Ontology approach, the wavefunction should be viewed as *nomological*—having to do with the laws characterizing the behavior of the matter in spacetime. These proposals highlight another form of underdetermination: different versions of the main interpretations are possible depending on how the wavefunction is viewed. The approach of Holland discussed by Bokulich may be seen as providing a new interpretation or a new version of Bohmian mechanics. Allori's Primitive Ontology approach yields a proliferation of variants of each of the main interpretations.

Thus, the problem of underdetermination is not resolved by settling on a preferred solution to the measurement problem. There are still questions about how to develop its formalism and ontology. Bokulich explicitly endorses pluralism about the quantum formalism and Allori, though she introduces a number of theoretical virtues to help winnow down the options, is left with two viable options (pilot-wave theory and GRWf). So, the problem of quantum underdetermination remains: there are multiple ways of telling a realist story about the quantum world that are at odds with one another.

2 Explanation

Perhaps quantum underdetermination requires a more radical rethink of what it is to interpret QM. If the trouble lies in giving a picture of the world described by QM, perhaps this should be excised from the interpretative enterprise. This would seem to lead straight to antirealism or instrumentalism, but advocates of pragmatist and QBist (formerly, Quantum Bayesian) approaches to QM reject these titles. On these views, QM is primarily understood as a user's guide for agents navigating their world—it tells them what to expect and how much credence to give certain predictions about the future. But, unlike familiar varieties of antirealism, some of these views seek to provide genuine *explanations* of predicted phenomena.

On Richard Healey's pragmatist view (ch.7), QM explains by rendering the explanandum expected and saying what it depends on. Suppose the explanandum is a measurement outcome. Then facts about the preparation procedure (specified in suitably non-quantum terms) and the quantum formalism yield a probabilistic prediction about the measurement outcome. This prediction should be treated as expert advice (in light of QM's instrumental success) and we should set our credences accordingly. If the prediction assigns a high probability to a certain outcome, then we should expect to find that outcome. So far, this is a purely epistemic explanation, but Healey seeks to go further: QM tells us that the outcome *depends* on the preparation in the usual counterfactual sense—an intervention on the preparation procedure would have led to reliable changes in the measurement outcome.

But there is something missing from Healey's explanation. What exactly is going on between preparation and measurement? Healey recognizes there is a gap here, but argues that it doesn't undermine his pragmatist approach's realist credentials: "The story provided by Newton's theory was not rejected as antirealist despite the fact that it included no mechanism filling the gaps between the sun and the earth on which it exerted a gravitational attraction" (p.125). But there is an important difference between the two kinds of gaps. Newton's is a case of action at a distance—there is a force operating between the sun and the earth instantaneously without anything mediating. But here there is a gap in both space and time—we can't say anything about the physical state of the system between its preparation and measurement. There is another difference as well: The quantum formalism seemingly represents the system during the intervening time. Of course, it's a contested matter exactly what the quantum formalism is telling us about the system in that time, but it's hard to see how an explanation that eschews any attempt to use that formalism to tell us about reality captures the spirit of scientific realism.

Indeed, as Peter Lewis (ch.9) argues, it's not just that pragmatist QM is uninformative about what's going in the gap, but it actually *precludes* claims about what might be happening. This is the result of Healey's adoption of an inferentialist semantics that ties content to environmental decoherence. This has the consequence that a non-quantum description is only possible when the quantum state of the system has suitably decohered. But gaps occur when the quantum state is coherent, and hence, pragmatist QM requires that non-quantum claims about the system during this period lack meaning.

Consideration of the formal results discussed by Wayne Myrvold (ch.12) leads to a parallel conclusion. Healey's pragmatism adopts a non-representational view of the quantum state, which functions only as an "informational bridge" connecting the non-quantum descriptions that provide the inputs and outputs of a quantum model [Healey, 2017]. Myrvold argues that recent no-go theorems [Pusey et al., 2012, Barrett et al., 2014] undermine anti-realism about the quantum state and he provides a weaker version of the crucial assumption on which their results rest. How can Healey's pragmatism avoid these results? The key lies in the Ontological Models framework used by the no-go theorems. This framework assumes that individual physical systems possess an underlying physical state and the quantum state reflects beliefs or information about it. Healey (and QBists) deny this, but doing so comes at a significant cost: One must deny not only that the quantum state represents the physical state of the system, but also that it represents beliefs or information about what the physical state might be. This reinforces the lesson that quantum pragmatism precludes description of—or even speculation about—physical reality except in special circumstances (e.g., measurement contexts).

Lina Jansson (ch.8) attempts to fortify Healey's pragmatist explanations while maintaining the idea that quantum models aren't representational. She claims that so long as the input into a quantum model is appropriate for the physical situation and allows for an epistemic explanation of the output, we have reason to think there's a worldly dependence relation between (the physical states associated with) the input and output. However, the worldly dependence Jansson invokes will still be "gappy" in the above sense. Jansson takes the ontic dependence in question to be non-causal, so the gap cannot be understood along the lines of the action at a distance found in Newtonian gravitation. Again, the question is whether an explanation that black-boxes the quantum formalism and focuses only on its inputs and outputs can be regarded as a satisfactory realist explanation. Regardless of terminology, such explanations are unlikely to satisfy realists motivated by the need to provide ontic explanations of phenomena in the scope of QM.

3 Fundamentality

The discussion so far has focused on interpretative issues as they arise in ordinary non-relativistic QM. Moving to quantum field theory (QFT) introduces new challenges for scientific realists. One source of trouble is the fact that a precise and mathematically rigorous treatment is only possible for *free* quantum fields, not the *interacting* fields required for treating (among other things) what goes on inside particle accelerators like the LHC. The version of interacting QFT used by physicists involves adding perturbation terms to a free field to approximate physical quantities that can then be compared with experiment. However, there's a technical problem with this approach: The terms in the perturbative expansion—a series of corrections to get ever closer to the real physics—fail to converge, leading to problematic infinities.

The solution to this problem is a process called renomalization, which involves imposing an energy cutoff, then reformulating the theory with new parameters that avoid the infinities. Originally, this process was viewed with suspicion—a bit of mathematical trickery that somehow generates empirically adequate predictions—but developments in renormalization have led to a shift in how the procedure is understood. And now, some philosophers argue that renomalization allows realists to explain the extraordinary instrumental success of QFT. The key insight is the idea of *universality*, the robustness of QFT under changes to the physics beyond the cutoff energy. Effective Realism views QFT as an *effective field theory* that only applies within a limited energy regime, but nevertheless offers a faithful picture of reality in that domain.

James Fraser (ch.14) argues, following [Williams, 2019], that renormalization allows us to understand QFT as a low-energy approximation of some unknown final (fundamental) theory. The robustness of QFT under changes of that underlying theory both explains why QFT works and identifies features of QFT worthy of realist commitment. However, Laura Ruetsche (ch.15) pushes back by noting that the class of underlying theories is not exhaustive, and hence, we cannot be sure that QFT is compatible with future physics. Moreover, she points out that the features identified by renomalization as being robust (e.g., low-energy correlation functions[1]) admit of an empiricist reading. This means that the Effective Realist must argue for a particular physical interpretation of these features to endorse, which allows the problem of underdetermination to resurface. Moreover, as J. Fraser notes, the measurement problem remains in QFT, and with it the problem of underdetermination discussed above.

Ruetsche argues for a humble empiricism toward QFT: "In experimentally-accessible regimes, [QFT] approximates [the unknown final theory] T_{final}'s predictions" (p.309). That is, rather than the realist's commitment to the approximate truth of QFT—i.e., that it approximates the unknown final theory—humble empiricism commits only to QFT's approximate empirical equivalence to the final theory. Note that in both cases, approximation is given a specific meaning as agreement in a certain low-energy regime.

However, while empiricism is certainly an option, realists will demand more of an explanation for QFT's success. *Why* does QFT approximate the predictions of T_{final}? A natural thought is that it approximates more than just T_{final}'s predictions. This is further supported by the robustness of certain features of QFT. If these features (e.g., low-energy correlation functions) can be given a realist treatment, then there's the potential for a deeper explanation of QFT's empirical success. It's not just that QFT makes the same predictions as the final theory, it also agrees with the final theory about certain features responsible for those predictions. Of course, the problem of the physical interpretation of these features remains, as well as Ruetsche's worry that the class of final theories considered is limited, but neither is insurmountable. The realist can argue for a particular physical interpretation of (e.g.,) correlation functions or else embrace pluralism about them. And granting that the robustness is limited, the realist should recognize that their commitments are fallible—leaving open the possibility that physics will develop in an unanticipated direction.

One promising option here is structural realism, which takes the mathemat-

---

[1] J. Fraser characterizes these as "expectation values of products of field operators associated with well-separated space-time regions" (p.286), cf. Ruetsche (p.306).

ical structures in our best theories to approximate physical structures in the world. In the case of QFT, the structural realist can (fallibly) endorse robust features of QFT such as the correlation functions without committing to a complete ontology tied to a particular interpretation. As long as there is something in the world with a structure that instantiates the correlation functions roughly as they're described by QFT, this provides an explanatory basis for QFT's empirical success. Moreover, their robustness provides good reason to think they will be preserved (at least as a low energy approximation) in future theories.

Doreen Fraser (ch.13), challenges the application of structural realism to QFT on the basis of purely formal analogies. She highlights the role of formal analogies with superconductivity in the development of the Higgs model. Initially, the presence of formal analogies may seem like grist for the mill of the structural realist, who abandons the standard realist's commitment to an ontology of individuals with intrinsic properties, about which formally similar theories will often differ. But, D. Fraser rejects the structural realist treatment of her case: "There are no physical analogies; the formal analogies do not map physical relations to physical relations of the same type. In particular, neither causal nor modal relations are preserved by the mappings, which precludes two prominent structural realist strategies for characterizing physical structure" (p.270).

While structural realism has often focused on causal or modal structure, these may not exhaust what qualifies as physical structure. The structural realist may insist that formal analogies are indicative of shared physical structure, even if that structure can only be characterized abstractly. So long as that structure is instantiated by a physical system, then it is *physical* structure despite our inability to characterize it in familiar causal or modal terms. Another way the structural realist may respond to D. Fraser's challenge is to reject the place of formal analogies in explaining the success of the Higgs model. One can grant that the analogy with superconductivity models was helpful in the development of the Higgs model—by correcting misconceptions about symmetry breaking—without it playing a role in explaining why the theory is successful. D. Fraser takes the realist explanandum to be the successful use of formal analogies, but another plausible target is the instrumental success of the Higgs model itself. If this is taken to be the explanandum, then it's not clear why the use of a purely formal analogy to clarify a misconception tells against the faithfulness of the representation provided by the Higgs model.

4 Conclusion

The challenges posed by underdetermination, explanation, and fundamentality remain unresolved. As a result, we must rethink both scientific realism and QM. This volume represents an excellent first step in this process and the questions it raises—some of which I've articulated above—serve as invitations for entry into this important area of philosophical exploration.

References

J. Barrett, E. G. Cavalcanti, R. Lal, and O. J. Maroney. No ψ-epistemic model can fully explain the indistinguishability of quantum states. *Physical review letters*, 112(25):250403, 2014.

R. Healey. Quantum states as objective informational bridges. *Foundations of Physics*, 47(2):161–173, 2017.

P. Holland. Computing the wavefunction from trajectories: Particles and wave pictures in quantum mechanics and thier relation. *Annals of Physics*, A 461: 3659–79, 2005.

M. F. Pusey, J. Barrett, and T. Rudolph. On the reality of the quantum state. *Nature Physics*, 8(6):475, 2012.

K. P. Stanford. *Exceeding our grasp: Science, history, and the problem of unconceived alternatives.* Oxford University Press, Oxford, 2006.

P. Williams. Scientific realism made effective. *The British Journal for the Philosophy of Science*, 70(1):209–237, 2019.