Critical notice: *The Quantum Revolution in Philosophy* (Richard Healey; Oxford University Press, 2017)

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Richard Healey's *The Quantum Revolution in Philosophy* is a terrific book, and yet I disagree with nearly all its main substantive conclusions. The purpose of this review is to say why the book is well worth your time if you have any interest in the interpretation of quantum theory or in the general philosophy of science, and yet why in the end I think Healey's ambitious project fails to achieve its full goals.

The quantum measurement problem is the central problem in philosophy of quantum mechanics, and arguably the most important issue in philosophy of physics more generally; not coincidentally, it has seen some of the field's best work, and some of its most effective engagement with physics. Yet the debate in the field largely now appears deadlocked: the last few years have seen developments in our understanding of many of the proposed solutions, but not much movement in the overall dialectic. This is perhaps clearest with a little distance: metaphysicians who need to refer to quantum mechanics increasingly tend to talk of "the three main interpretations" (they mean: de Broglie and Bohm's hidden variable theory; Ghirardi, Rimini and Weber's ('GRW') dynamical-collapse theory; Everett's many-universes theory) and couch their discussions so as to be, as much as possible, equally valid for any of those three. It is not infrequent for philosophers of physics to use the familiar framework of underdetermination of theory by evidence to discuss the measurement problem.

If we get a little distance in a different direction, we can also see that this discussion overlaps only slightly with the discussions in *physics* about the measurement problem, which (after decades of neglect, bordering on censorship) are in some quarters of the field quite vibrant. The Everett interpretation is advocated by a reasonable-sized constituency of physicists (mostly in high-energy physics and quantum cosmology) but the other two "main interpretations" are largely ignored. In their place, physicists discuss a range of strategies which receive only limited attention from philosophers: variants of Bohr's and Heisenberg's ideas; strategies motivated by information theory and by Bayesian interpretations of statistical mechanics; strategies which try to modify the Newtonian picture of a single unequivocal description of the Universe; strategies which try to take seriously a conceptually central role for observation and measurement, without descending into mysterian speculations about consciousness. To a quite substantial extent, physicists and philosophers with an interest in the measurement problem are talking past each other.

It is not difficult to see why this is. The majority of contemporary philosophers of quantum mechanics, including most advocates of "the three main interpretations" adopt a fairly uncritical scientific realism, imported from general philosophy of science with at most limited patience for how that realism ought to be modified in the face of quantum theory. From this perspective, the lesson that the measurement problem teaches is a lesson of physics, a sharp reminder that something is wrong with our supposedly-best physical theory; the solution, likewise, is more physics, a change of quantum theory into some more satisfactory physical theory.

(This account is clearest for advocates of the de Broglie-Bohm and GRW theory, many of whom are quite explicit that they think modern physics has lost its way and needs a reminder by philosophers to do better; it is more complicated and equivocal for the Everett interpretation, both because of the latter's close ties to structuralist ideas in philosophy of science and because arguably the Everett interpretation does not change the quantum formalism. But most defenses of the Everett interpretation (including some of my own) do still adopt that "fairly uncritical scientific realism".)

Conversely, while physicists who write on the measurement problem often hope their work will lead to new directions and new perspectives in physics, they only very seldom contemplate modifying the quantum formalism. For them, the lesson of the measurement problem is a lesson in philosophy: it teaches us not that our physics needs modifying but that our philosophical conception of a scientific theory, and indeed of the world, is outdated and needs to be changed to come in line with our best physics.

It's tempting for sophisticated philosophers of physics to react with complacency. "Yes, physicists speculate about philosophical lessons to be learned", they may say, "but those speculations are born of naivete and ignorance". And indeed, there is much that is naïve and underinformed about physicists' philosophical proposals for the measurement problem. Yet some humility is in order. For one thing, physicists react similarly to proposals to change the formalism of quantum mechanics, for similar reasons and with much justification (in my experience, most advocates within philosophy of strategies like GRW or de Broglie-Bohm have no idea just how vast is the gulf between the domain of applicability of these theories and the full domain of applicability of quantum theory). For another, the formalism of quantum mechanics has stood unaltered for ninety years, and has been accepted during that period by the overwhelming majority of physicists. The conventional wisdom in philosophy of science has changed out of recognition over that same period, from the logical empiricism of Carnap and the pragmatism of Quine, to contemporary scientific realism with its close ties to analytic metaphysics. And that "conventional wisdom" has, through that period, been a majority view but scarcely a consensus, with some of the most influential figures in the field (e.g., van Fraassen, Cartwright) opposing it. At the very least, it cannot be *obvious* that the way to a solution of the measurement problem is through changing our physics rather than changing our philosophy. And if changing philosophy is an option, it is likewise not obvious that the skills of philosophers are best deployed almost entirely in exploration of the change-the-physics option.

And this is why I found *The Quantum Revolution in Philosophy* such a breath of fresh air. Healey himself is a dissenter from the current conventional wisdom, an advocate of American pragmatism in general philosophy, and he seeks to construct an interpretation of quantum mechanics built around the insights of pragmatism, and then in turn to let that interpretation, and quantum mechanics more generally, provide lessons for philosophy in general.

The book has two main parts: the first explains quantum mechanics *a la* Healey, without assuming any prior knowledge of the physics (an Appendix develops some mathematical details) and the second explores its interpretational and philosophical consequences. In between these two parts, a short Interlude briefly discusses other interpretations of quantum mechanics.

Healey states in the introduction that he had intended the first part of the book to be neutral as to the interpretation of quantum mechanics, but that in the writing he found this to be impossible (I sympathize). Echoes of this show in the final book: the first three chapters of Part One more or less do stay interpretation-neutral, and do an exceptional job of presenting the quantum theory in a way which non-specialists can follow. (I admit to being skeptical that anyone can understand quantum theory sufficiently well to critically assess its interpretations simply based on this sort of account, but Healey does as good a job as I've seen of trying to prove me wrong.)

In the second half of Part One we begin to see the distinctive features of Healey's approach, when he considers how to interpret the quantum state. He identifies two conventional readings of the state – as directly representational of a physical system's properties (akin to the phase-space points of classical mechanics) and as describing probability distributions over some as-yet unknown micro-ontology (akin to phase-space *distributions* in classical mechanics). This is roughly the distinction that physicists (following Harrigan and Spekkens, 2010) refer to as *psi-ontic* vs *psi-epistemic* (though Healey does not use this terminology). Most of the classic 'realist' interpretations of quantum mechanics – Everett's, de Broglie and Bohm's, the various dynamical-collapse theories, the textbook Dirac-von Neumann interpretation – are psi-ontic (albeit in some the quantum state is taken as representing dispositional or nomic rather than categorical properties). Psi-epistemic approaches are rare in the modern debate, since most participants see no-go results like the Kochen-Specker theorem (Kochen and Specker, 1967) and the more recent PBR theorem (Pusey, Barrett and Rudolph, 2013) as ruling them out, but historically this was Einstein's own preferred approach, and it still has adherents (Spekkens himself, for one).

Healey's proposed third way is to interpret the quantum state *prescriptively*: it provides advice to an agent as to what probabilities – understood as rational credences – should be assigned to outcomes. In this sense (which is very much in accord with the broader pragmatist tradition) a quantum state functions something like an expert, to whom the wise will defer in making their own judgements. But except in special cases, these prescribed credences cannot be reduced to the sort of univocal probability measure over underlying goings-on that the psi-epistemicist has in mind.

Now, the idea of a third way is by no means new. The idea that the quantum state generates probabilities, without any prospect of an underlying micro-ontology for the probabilities to be assigned to, goes back to (at least some interpretations of) Bohr and Heisenberg, and is fairly explicitly adopted in the modern operationalism of Peres (Peres, 1993; Fuchs and Peres, 2000) and of the evolving quantum-Bayesian / QBist approaches developed by Caves, Fuchs, Schack and Mermin (Caves, Fuchs and Schack, 2007; Fuchs, Mermin and Schack, 2014); arguably it is also the view adopted by non-Everettian advocates of consistent-histories like Griffiths and Omnes (Omnes, 1988; Griffiths, 2013). One weakness of the book is a lack of sustained engagement with these related views, some of which are cited briefly in an introductory footnote but none of which receive any real discussion. One can get the impression from reading Healey that his approach breaks a previously unbroken consensus that the psi-ontic/psi-epistemic dichotomy exhausts the possibilities, which is not fully true even in the philosophy literature (see, e.g., Bub and Pitowski, 2010) and not at all true for the physics literature.

Turning this around, for philosophers sympathetic to the overall contours of Healey's approach there is profitable work to be done in clarifying the relation between the specific proposal Healey makes and these alternatives. To take one example: QBists claim that the first-personal nature of their account of reality is central to their bypassing of Bell's inequality; Healey also claims to reconcile locality with Bell inequality violation; his account likewise makes some use of the fact that quantum states, as prescriptions, are relativized to agents; I'm not clear what the relation between these approaches are, but they seem at least to overlap.

In any case, if one sets aside the issue of relation to other views, Part One of Healey's book does a very good job both of presenting the general structure of quantum mechanics and of explaining the distinctive features of his own approach; the philosophically informed reader is left with many questions, but the answers are the task of Part Two.

Before that, however, comes Healey's interlude, focused on "the three main interpretations". In my assessment, this is the weakest part of the book. Partly that reflects awkwardness about its intended role, and intended audience: the criticisms it raises are fairly obviously aimed at readers who already have some familiarity with these approaches (indeed, neophytes are advised to skip the chapter entirely) and yet are spelled out too briefly to be likely to change minds among the cognoscenti. Perhaps the most natural understanding of the chapter is as part of the overall dialectic, explaining at least why Healey rejects these approaches, and yet the natural reading of the rest of the book is that Healey is led to his own interpretation not simply through desperation at the lack of realist alternatives but though active enthusiasm about its benefits.

The other problem with the Interlude is its rather awkward framing device, whereby the strategies it discusses are described as worthwhile projects to develop *alternatives* to quantum mechanics but not as interpretations *of* quantum mechanics. In many places that reads as if Healey means that these interpretations, unlike his, are unavailable as interpretations of the quantum *formalism*, but he recognizes that that's not really defensible, and in various places makes clear that he means that none of these strategies are available as interpretations of quantum mechanics *as he understands it.* Put that way, the claim is true by definition, and so rather uninformative: an advocate of the Everett interpretation could just as well claim that Healey's program is available as an alternative to quantum mechanics but not as an interpretation of quantum mechanics, since the latter definitionally has to be interpreted *a la* Everett. (I *am* an advocate of the Everett interpretation, but I'm happy to concede that Healey's approach is an interpretation of quantum mechanics while dynamical-collapse theories and the de Broglie-Bohm theory are alternatives to quantum mechanics, because all I require of pure interpretations is that they leave the quantum formalism unmodified.)

The real content of the book lies in the exceptionally rich Part Two, in which the more philosophical aspects of Healey's approach are explored. The ideas here generate a great deal of work for philosophers, both those broadly sympathetic to Healey and those more critical: there is far too much here for me to systematically do it justice. In the rest of this review I will consider some related topics addressed in this section concerning representation, operationalism, and the quantum/classical divide; not coincidentally, my concerns about these topics are the main reasons why, despite my admiration for Healey's work, I remain unconvinced by its conclusions.

Firstly, in Healey's account a central role is played by what we might call "non-quantum physical magnitudes" (NQPMs), which Healey regards as the representational content of a physical description (as opposed to the quantum state, amplitudes etc, which are to be understood as expert advice to an agent as to what beliefs to have as to the values of the NQPMs). I should clarify that Healey's account of representation is itself pragmatist, so what he means here is somewhat different from what others mean; still, the NQPMs are importantly distinct from the quantum state, and central to Healey's overall proposal. Yet in reading and re-reading Part Two I was left unclear about just what the NQPMs actually are. I know that they are defined by a subset of the self-adjoint operators, and that a value of physical magnitude corresponding to operator X is an eigenvalue of X (with the Born rule defining a probability rule over those eigenvalues), but the Kochen-Specker theorem tells us that it must be a proper subset. Which proper subset? Some possibilities:

a) Healey says (p.137) that representational statements in physics are "statements about physical entities and magnitudes acknowledged by the rest of physics, not statements about physical entities and magnitudes newly represented in quantum theory”. A very natural way to read this is that they’re determined by the physical theories that are not quantum-mechanical. But there aren’t really any such theories, as Healey surely knows: quantum mechanics is a dynamical framework theory, like classical mechanics, and all our concrete dynamical theories are either quantum or classical – and in the latter case, almost without exception, physicists regard the latter as really quantum theories in regimes where quantum corrections can be neglected.

b) Another way to read this quote is that the magnitudes are all the dynamical variables that turn up in those concrete dynamical theories – field configuration values, particle numbers, energy and momentum densities, and the like. But again, there are far too many of these to assign values to all of them simultaneously, given the Kochen-Specker theorem.

c) Yet a third way is to regard the “rest of physics” as *classical* physics. I think there’s a *prima facie* pretty cogent version of Healey’s position that takes this line: it’s pretty close to Bohr (where the representational role is played by classical physics and the content of QM cannot be understood without classical physics), and also very close to a line defended by Peres. But textually it looks unlikely that Healey intends this.

d) I think the right textual reading of Healey is that the magnitudes are those picked out by decoherence, i.e. those for which a consistent probabilistic reading is possible. But I don’t think mere decoherence – that is, the suppression of interference – is sufficient to specify the variables uniquely. As Dowker and Kent (1996) demonstrate, that condition is satisfied by vast numbers of different, incompatible choices of magnitude. Gell-Mann and Hartle (1993) use the emergence of robust quasi-classical dynamics to pick out a preferred decoherent history space (and modern Everettians like me use their approach explicitly). But I’m not sure whether Healey’s non-representational reading of QM permits him to adopt this approach, and at any rate there’s no textual evidence that he wishes to; nor is there textual evidence that he wants to adopt the kind of contextualism about the decoherence-selected observables that Griffiths or Omnes are willing to espouse.

In any case, I don’t think Healey fully succeeds in saying what the non-quantum physical magnitudes actually are.

Secondly, Healey contrasts quantum and classical physics in several places, and rejects (p.241) the usual elementary derivation of the latter from the former via Ehrenfest’s theorem. (He regards the equations of motion in classical mechanics as dynamical and representational, unlike those of quantum mechanics). Now, in the first place he is not doing justice to a very large body of mathematical and conceptual work on the quantum/classical transition, going far beyond Ehrenfest’s theorem (indeed, much of the development of decoherence was explicitly motivated by the attempt to understand the transition). But more fundamentally, I’m not sure what Healey actually thinks about the systems that we describe today through “classical” physics. I’m struck again that one natural reading of his approach is the Bohrian strategy, where classical and quantum are fundamentally distinct and the reduction of one to the other is rejected or at least finessed. But if he doesn’t think that, but accepts the usual physics line, then even apparently “classical” systems are just quantum systems in the large-action regime, and the equations of motion that classical objects obey (being just limiting cases of the Schrodinger equation) aren’t dynamical equations at all. (So Newton’s law, for instance, is also simply advice from an expert to an agent interesting in making predictions about the planets.) I’m genuinely unsure what Healey thinks here; if he doesn’t want to accept a Bohrian classical/quantum dichotomy, I don’t know how he avoids the conclusion that there’s no such thing as dynamics at all, *anywhere* in physics.

Thirdly, Healey is at pains to insist that his account is not operationalist (this is one way in which his account differs from the quantum Bayesians and (neo-)Heisenbergians, who embrace at least a form of operationalism). But at the least, his 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). The standard line in particle physics is that the top quark and Higgs boson, in particular, are dynamically emergent via analysis of the excitations of various coupled fields in the dynamics of the standard model. But to Healey, the equations of the Standard model don't represent dynamics at all: they are simply rules for updating the advice we are given for predictions over time. So it's opaque to me how Healey avoids just regarding the Standard Model as a calculational black box to relate one lot of macro-level phenomena to another, just as Heisenberg did. (Even the alpha particles to which he refers in his discussion of Rutherford seem a little dubious, though probably one can appeal to some kind of decoherence-based account there.)

Similarly, Healey writes (p.138) of the "quantum fluctuations that may account for the large-scale distribution of matter in the very early universe", and in doing so he recounts standard cosmology. But it's opaque how this can be recovered in his framework. A "quantum fluctuation" is a property of the state; on Healey's account, this is just advice to the agent, and can't be causally responsible for anything, least of all features of the early universe billions of years before the agent's birth.

Finally – though relatedly – the pragmatist account Healey gives of explanation is sharply at variance with the way in which explanations are normally given in mainstream contemporary physics. The standard mode of explanation in non-classical physics – of why nuclear fusion in the Sun occurs at the temperature it does; of why semiconductors work; of why helium-4 forms a superfluid when helium-3 doesn't; of why gold is the color it is; of why matter is stable – is phrased in terms of the Hamiltonians of systems and the evolution of states under those Hamiltonians. Healey's discussion of explanation is rich but seems to engage mostly with quantum processes understood abstractly (in the fashion of quantum information). It would be instructive to see how a Healey-type pragmatist handles a more concrete example – in all the cases I list, quantum mechanics is not an overlay on top of the underlying representational account but the language in which that account is given. And if the pragmatist cannot give any such account but regards QM as a calculational black box in these cases, we seem back to operationalism or at least to the Copenhagen picture of QM as a calculational overlay on an underlying classical account. Healey's rich use of the language of contemporary physics suggests he would not wish to make this move – but I don't see how he can avoid it.

These fairly sceptical remarks may seem to undermine my earlier claims about the value of Healey's book. Really, though, the two go hand in hand. The problem with the uncritical realism adopted in too much of the philosophy of physics literature is not that it is *realism* but that it is *uncritical.* Insofar as the arguments for realism are any good, that is not because alternatives to realism represent some unseriousness or lack of nerve on the part of realism's critics, but because those alternatives lack the resources to do justice to science as we find it. That was the hard-earned lesson learned from the fall of logical postitivism and logical empiricism, and a lesson too-often forgotten in modern work. Healey's book is a salutary lesson to all: to sceptics about the realist trend in modern philosophy of science, who should be encouraged that alternative philosophical strategies may earn their keep through their engagement with the measurement problem; to defenders of that trend, who should be reminded that the arguments for realism need to be constantly remade and reassessed in the light of the best physics that we have.

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