Review of "Interpreting Quantum Theories" by Laura Ruetsche

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Interpreting Quantum Theories is a subtle book. Its primary goal is to adduce evidence for a rather general thesis in philosophy of science: that the "interpretation" of a physical theory (by which Ruetsche means, roughly, which parts of the theory correspond to physical facts about the world, and relatedly, what states of affairs are possible according to the theory) cannot be established once and for all, but depends on situational and pragmatic factors. That is: how we interpret a given theory will depend what particular representational task the theory is being used to do in a particular circumstance: which set of physical phenomena it is being used to model. Ruetsche (correctly, in my view) claims that this is not the general model of interpretation that we use in philosophy of science: in general we seek what she calls "pristine" interpretations, which tell us how a theory corresponds to the world once-and-for-all.

With that goal, one might expect a comparably general discussion in philosophy of science, perhaps drawing on specific examples but mostly carried out at a rather high level of generality. The book is nothing of the kind: Ruetsche's evidence is drawn exclusively from quantum theory, and specifically from the quantum theory of systems with infinitely many degrees of freedom, which she calls QM_∞. Theories of this kind find two main uses in physics: statistical mechanics in the thermodynamic limit (where the systems in question are taken to be spatially infinite) and the quantized theory of fields (QFT), which (roughly speaking) associates field observables to every spacetime point, and so requires an infinity of degrees of freedom even when confined to a finite volume (but which is usually also studied in the infinite-volume limit).

QM_∞ systems generate substantial mathematical difficulties over and above those associated with ordinary quantum mechanics. Mainstream physics has dealt with these by a variety of techniques of debatable mathematical coherence (many of which are collected together under the term *renormalisation*). But the bulk of philosophical work in QM_∞ (at least in the last 10-15 years) has pursued a different strategy which requires at the outset that the theories being discussed are formulated in a fully mathematically rigorous way. Ruetsche (one of the main pioneers of this philosophical research program) is up-front about the cost of this strategy: much of contemporary physics fits uneasily at best within it, and in particular the empirical results of particle physics cannot at present be incorporated within it. She is equally clear about the rationale for doing so: the philosophical project on which she is engaged — how to *interpret* a given theory — cannot get off the ground without some theory to interpret. Fair enough (though I will return to this issue at the end).

The interpretational problem for QM_∞ is basically as follows. We can characterise normal (finitely-many-degrees-of-freedom) quantum mechanics in two ways: algebraically (regarding observables as abstract algebraic entities, and states as linear functionals from observables to expectation values) and via Hilbert space (regarding observables as self-adjoint operators on some Hilbert space, and states as vectors (or rays, or operators) in the same Hilbert space. The Stone-von Neumann theorem tells us that on reasonable assumptions[1] these two approaches are equivalent — provided that there are only finitely many degrees of freedom. In QM_∞ the two come apart (each algebraically-specified theory determines uncountably many mathematically non-isomorphic Hilbert-space theories), creating a space of possible alternative interpretations of any given QM_∞. Ruetsche identifies, in particular, several 'pristine' interpretations, including (but not limited to) "algebraic imperialism" (in whch the algebraic approach is prioritised) and "Hilbert space conservatism" (which selects a specific one of the vast number of Hilbert-space representations of a given QM_∞). Her task for most of the rest of the book is to undermine the traditional philosophers' strategy of arguing which is the right pristine interpretation. Instead (Ruetsche attempts to show), fealty to the actual *uses* of QM_∞ in physics requires us to move between these various ways of interpreting a theory according to the particular context in mind.

She does so, in the main, through two sets of case studies, each worked out across several chapters. The first concerns the nature of particles in quantum field theory where most strategies for choosing a preferred Hilbert-space representation make heavy use of a basis of definite-particle-number states. It has become fairly well known that this strategy runs into difficulties in some exotic situations (such as black hole radiation) and that this puts pressure on Hilbert-Space conservatism. But Ruetsche both strengthens and pushes this case, and also shows that particle considerations create serious difficulties for Algebraic Imperialism too.

The second set of case studies deal with spontaneous symmetry breaking: the phenomenon where a symmetry of the underlying dynamics is hidden at the level of phenomenology. Spontaneous symmetry breaking occurs both in condensed matter physics (where it is responsible for phenomena like superconductivity and ferromagnetism) and in particle physics (where its most famous manifestation is the "Higgs mechanism" that is believed to give rise to the mass of elementary particles. Here too, Ruetsche makes a strong case that no single interpretation does full justice to the way the phenomenon is studied and represented.

These two topics, between them, require Ruetsche to engage with a fairly large fraction of the philosophical literature of QM_∞ over the last 15 ears.

[1] Ruetsche spends part of one chapter considering just how reasonable these assumptions are — and puts some pressure on them — but they are not her main target.

In both cases, her account both presents an accessible account of a complex and technical field, and links and connects the various pieces of work together in support of her overall theme. And this brings up what is effectively the book's other major value: it is, far and away, the best available route for a newcomer to engage with this difficult and inaccessible area. Ruetsche has a superb sense for when technical detail is needed and when it can be skipped or simplified; she is not at all afraid to give rough sketches of results (accompanied by appropriate references) where the precisely-stated version would just add clutter. I couldn't call *Interpreting Quantum Theories* easy reading, even by the standards of philosophy of physics, but it is easier reading than I would hve thought possible, without compromising its arguments. The book is likely to see wide use as a starting point for further work in the field even by those unpersuaded by (or uninterested in) its main thesis.

I'll make three critical comments, of rather different natures. Firstly, in a book about the interpretation of QM it's natural to expect some discussion of the quantum measurement problem, and Ruetsche does not disappoint: she treats "interpretation" in her sense as including the more standard sense of "interpretation" in which the Everett and Copenhagen interpretations, dynamical collapse theories, and hidden-variable theories are all called interpretations, and devotes a chapter to making the case that these various interpretations are also undermined by QM_∞. I wasn't convinced: Ruetsche's argument requires various very different strategies for solving the measurement problem to be fitted into a certain framework in a rather Procrustean fashion. My own reading was that "interpretation" in Ruetsche's sense largely comes apart from "solution to the measurement problem", and engaged with the rest of the book on that basis. Indeed, the bulk of Ruetsche's discussion seemed largely neutral to how QM is interpreted in the measurement-problem sense, at least from the point of view of those interpretations (such as Bohr's, or Everett's) that leave the quantum formalism unchanged.

Secondly, there is some tension between Ruetsche's desire to pay attention to the details of actual applications of QM_∞, and her insistance on a level of mathematical rigor that rules out of consideration virtually all empirically-connected work on these theories (Ruetsche's examples of applications are mostly from the mathematical physics literature, and mostly rather remote from experiment). But this is probably unavoidable given the overall framework she adopts — and she is generally willing to drop her requirements for rigor when urgently necessary (this is particularly evident in her discussion of spontaneous symmetry breaking in particle physics).

The final "criticism" is more of a question for further study. Ruetsche makes a powerful case that the interpretation of QM_∞ is situation-dependent. But the way is open for those who want pristine strategies to attribute this dependence to the existience of infinities in the theory. Insofar as infinity enters our theories only as an unphysical idealisation or abstraction, it would be unsurprising and harmless if it turned out that the right way to carry out that abstraction is situation-dependent. The thermodynamic limit is certainly unphysical in this sense, and this is part of Ruetsche's motivation (in her discussion of symmetry breaking) to move to the context of particle physics. Here too, though, I suspect that the bulk of physicists (though probably not the bulk of philosophers studying QFT) would regard the infinities there in similar fashion. But no doubt any particular set of case studies could be criticised in some such way. If Ruetsche's general thesis is right, presumably case studies of comparable detail in other areas of physics will show it up there too and further strengthen the case; even if the *general* thesis is wrong, the light cast on idealisations and on appeal to infinity is extremely valuable.

All in all, the book is a remarkable achievement: at one and the same time a cohesive account of a major body of work by the author and others, an accessible and philosophically sensitive introduction to the field, a powerful defence of a largely novel position in philosophy of science through careful attention to scientific details, and an impressive advertisement for the value of that strategy in philosophy of science that places a high premium on mathematical rigor without losing focus on the philosophical issues at hand. It's not the only strategy available, but in Ruetsche's hands at least, it is remarkably effective.