BOOK REVIEW

Laura Ruetsche, ***Interpreting Quantum Theories***. Oxford: Oxford University Press (2011), xvii+379 pp., $75.00.

I expect this extremely rich and engagingly written book to prove seminal in three ways. It is an excellent (and currently the only) introduction for philosophers to the formalism of quantum theories permitting unitarily inequivalent representations of the fundamental commutation relations. It significantly furthers our understanding of quantum field theory and quantum statistical mechanics in the thermodynamic limit. And it does all this in the course of an extended argument for a kind of interpretive pluralism that challenges not only key tenets of scientific realism but also framework assumptions realists share with their philosophical opponents.

Since the mathematics of a C*-algebraic formulation of quantum theory are not part of the skill set of the typical philosopher of science, it is appropriate to begin by asking what could motivate him or her to read this book. Ruetsche gives a convincing answer in its first and last chapters. Debates concerning scientific realism, physical possibility, and laws of nature all too often proceed at a level of abstraction far removed from the details of actual scientific theories. Just as the field studies of Darwin and Wallace revolutionized biological thought, a close examination of how some of our most successful physical theories manifest their fitness may reset the terms of such debates in philosophy of science.

The scientific realist takes a physical theory's success as a powerful reason to believe the physical world is pretty much how that theory says it is—not just the way it will appear to us. After identifying the content of a theory with the world structures its models represent, the recommended belief is that our world is (basically) structured in one of these ways. Constructive empiricists and other antirealists demur while accepting the identification. They may then join forces with the realist in the prior interpretive project of delineating the set of a theory's models and saying just what kind of possible world each represents. By doing so they endorse what Ruetsche calls the pristine approach to interpretation—an approach that she argues against in this book.

The argument emerges gradually in the course of her detailed investigation of the structure and applications of quantum theories of systems with an infinite number of degrees of freedom (QM_∞). What this reveals is that the applications of a theory of QM_∞ adulterate the set of its models, so this set has no application-independent extension. It thereby introduces a pragmatic element into the interpretive enterprise that threatens a key presupposition of debates concerning scientific realism.

If quantum theory was born in 1900 (with Planck the reluctant midwife), it was reborn not once but twice a quarter of a century later in Heisenberg's matrix mechanics and Schrödinger's wave mechanics. A key theorem due to Stone and von Neumann established a precise sense in which their theories are equivalent: very roughly, they correspond to unitarily equivalent representations of the same basic Heisenberg commutation relations.[1] Forms of quantum theory familiar to many philosophers of science (as well as generations of undergraduate physics students) all fall within the scope of this theorem. But quantum field theories and quantum statistical mechanics in the thermodynamic limit do not: here the basic commutation relations admit continuously many unitarily *in*equivalent Hilbert space representations. These are not related to one another like representations of a single vector state by configuration- and momentum-space wave functions. But by a further level of abstraction each represents the same C* algebraic structure generated by (the Weyl form of) the basic commutation relations.

A pristine interpreter of a theory of QM_∞ can (i) take that theory to splinter into infinitely many theories, each corresponding to a distinct unitary-equivalence class of Hilbert space representations, (ii) take as target the abstract C* algebra and states these all instantiate, or (iii) focus on a single Hilbert space representation cobbled together out of all these representations. Ruetsche argues that none of these options is able to account for the descriptive and explanatory successes of theories of QM_∞. Like the chameleon, a theory of QM_∞ succeeds by adapting its colors (model class) to its environment. In her own analogies: "A theory that underdetermines its own interpretation is like a healthy breeding population: it has a shot at enough diversity to (under some interpretation or other) meet the variety of demands its scientific environment places on it. Like survival, 'empirical success' is a convoluted, chancy and conditioned thing. Like genetic diversity, possibility pragmatized situates its possessor to respond successfully to the changing circumstances on which its survival depends" (355). This kind of success cannot support scientific realism—realism about what?

Some philosophers of physics may regard my focus so far on the philosophical argument of the chapters sandwiching the book to have mistaken the bread for the meat it contains. Whatever one thinks about that argument, this book provides a feast for those hungry to penetrate the mysteries of von Neumann algebras, GNS representations of C* algebras, algebraic

1. Ruetsche gives a precise statement of the theorem (41) after patiently explaining exactly what it says and why it matters.

and axiomatic quantum field theory, KMS states, DHR selection theory, and "a modicum of modular theory." There is now a substantial body of work by philosophers as well as mathematical physicists making clear the importance of these concepts for foundational questions concerning quantum field theory and quantum statistical mechanics. But this is largely confined to journal articles and specialist handbooks and demands acquaintance with mathematics beyond that with which most philosophers of science have become familiar in their attempts to interpret "ordinary" quantum mechanics. Ruetsche's book breaks new ground as the first work to introduce philosophers to the mathematical structures involved in what she calls extraordinary quantum theories and to the fascinating conceptual problems these raise. As she explains, far from easing well-known problems involved in interpreting ordinary quantum mechanics, extraordinary quantum theories intensify some while posing new ones.

It is a brilliantly successful introduction. Ruetsche gets the level and tone just right. She patiently explains important theorems and motivates important technical definitions, while leaving unimportant details to footnotes that include copious references for those who demand them. There is plenty of rigorous argument here, but where rigor would distract or unnecessarily intimidate, it is replaced by what she calls "argument" or "gistification." And she manages to leaven her presentation with an attractive and often amusing writing style rarely encountered in presentations of such material. One is reminded of the best kind of coach—demanding but always encouraging, and leading by example. She has prepared the way for others to follow into this unfamiliar and perhaps forbidding territory.

Two simple physical systems serve as paradigms for Ruetsche. She repeatedly refers to an infinite chain of spin half systems in her discussion of quantum statistical mechanics and to a free Klein-Gordon field as an exemplar for quantum field theory. While serving her didactic purposes well, these systems have few practical applications in physics. Actual physical applications of theories of QM_∞ present complexities that challenge her general line of argument in the book, as I shall explain.

Chapter 1 is followed by seven chapters setting up the mathematical and conceptual framework of the rest of the book. Ruetsche first applies this framework to the vexed question of the status of particles in relativistic quantum field theories. Her conclusion? "Is particle physics particle physics? The answer I've tried to support is: sometimes it might be" (260). She argues that a relativistic quantum field theory admits a fundamental particle interpretation only in very special circumstances and that this spells trouble for a pristine interpretation of a theory of QM_∞ that confines its states to a single Fock space. Unlike excitations of a free, massive Klein-Gordon field in Minkowski space-time, neither the protons colliding at CERN nor the Standard Model "particles" whose properties they elicit count as fundamental particles on this reckoning. These chapters serve as an excellent introduction to important contemporary work by philosophers of physics. All naturalistically inclined ontologists should be required to read them.

Next she switches attention to quantum statistical mechanics in the thermodynamic limit, where the number of subsystems tends to infinity while their density remains constant. Here only the "extraordinary" quantum theories of QM_∞ can accommodate the presence of distinct phases in equilibrium and aspire to explain phase changes as instances of broken symmetry. She constructs a Coalesced Structures Argument against pristine interpretations of these theories but acknowledges its vulnerability to the mistaken idealization objection—no cup of tea or other thermodynamic system is really infinite.

The penultimate chapter tries to evade this objection by appeal to broken symmetries of the actually infinite quantum field systems of the Standard Model. But she freely admits her inability to account for the operation of the elusive Higgs mechanism within the mathematical framework developed earlier in the book. (As far as I know, no such account is available: I consider it an open question whether this casts doubt on the framework or the operation of the mechanism.) To rescue the Coalesced Structures Argument she returns to thermodynamics and argues that the coalesced structures are real because they are both likely to figure in future theories as well as essential to the success of our present explanatory activities based on theories of QM_∞. I'm glad I own two copies of this book: one is liable to disintegrate through overuse!

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