Review for *Philosophy of Science*; file 99.7.7.1b

Quantum Chance and Non-Locality

W. Michael Dickson, *Quantum Chance and Non-Locality: Probability and Non-Locality in the Interpretations of Quantum Mechanics*. Cambridge: Cambridge University Press, 1998. Pp. xix + 244. US$??. ISBN: 0 521 58127 3.

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This is an excellent book, by one of the philosophy of quantum theory's brightest stars. It combines a clear presentation of determinism, probability and non-locality in several current interpretations of quantum theory, with a good deal of detailed analysis, both reporting other people's and Dickson's own results, and developing his own ideas—which are often heterodox, but always well-defended and thought-provoking. The treatment is often concise, especially when reporting standard material or others' results. There are also frequent changes of gear; both because the issues are complexly related to each other, and because Dickson sensibly does not aim for a definitive treatment of issues that are at present so controversial—accordingly, he weaves about, not forcing his material into some single line of argument. So this is a monograph, not a textbook for teaching or a treatise summing up a conquered field. But the style is clear and vigourous; the book is packed with information (sometimes about ancillary issues); and as we shall see, Dickson *does* have some provocative main claims, if not an overarching single line of argument. In this short space, I can only praise the book's general virtues and state some of the main claims.

Dickson's combining the presentation of current interpretations of quantum theory, with development of his own ideas, is all the more impressive in the light of the fact that in recent years, activity in the philosophy of quantum theory has burgeoned, partly as a result of close contact with the foundations community within physics. More specifically, the last fifteen years have seen several developments which bear directly on the book's topics. Dickson discusses in detail what I take to be the three main developments: (i) dynamical reduction theories; (ii) the pilot-wave theory; (iii) the various modal interpretations of quantum theory. (Of course there have been other developments, such as new proofs of nonlocality, in the styles of Greenberger et al. and of Hardy; to say nothing of the whole new field of quantum cryptography and computing. But I suspect Dickson is right not to pursue these: the main new lessons for interpretative issues about probability and non-locality probably lie in (i) to (iii).)

Not only does Dickson discuss these three developments; so far as I know, his book is the first of its type, within philosophy of quantum theory, to do so. Certainly several otherwise excellent books of the last ten years do not match Dickson's coverage of (i) to (iii) in width and depth. But Dickson's coverage is not motivated just by (i) to (iii)'s intrinsic importance. He has both a general view, and several specific claims, guiding his choice of topics and informing his conclusions.

The general view, which Dickson emphasises several times, is that we cannot expect answers to such questions as whether quantum non-locality involves superluminal causation, or is compatible with special relativity: and this is not only because we need to specify a sense of causation, or what we understand by the requirements of special relativity—we also need to specify an interpretation of quantum theory. That is surely right; and though it is now hardly disputed within philosophy of quantum theory, it is worth emphasising (admitting!) to oustiders to the field. For as I recall, twenty years ago there was a widespread hope that one could get such answers, given only a specified sense of causation and of relativity, i.e. without having to address the off-puttingly hard problem of quantum measurement, and so without having to commit oneself to an interpretation of quantum theory.

Accordingly, the book is split into two Parts: Part One develops several interpretations, especially as regards their treatment of probability and determinism; and Part Two discusses their treatment of non-locality. By and large, Part One, called 'Quantum chance' and comprising Chapters 1 to 5, is more expository and less controversial than Part Two. It discusses 'orthodox quantum theory' (with the projection postulate applied at measurements) and Everettian interpretations, as well as the interpretations labelled (i) to (iii) above. For me, highlights of this Part included: (a) by way of exposition, Dickson's discussion of the work of Dürr et al. and of Valentini, about how to justify the pilot-wave theory's postulate that configurations are probabilistically distributed in accordance with the Born rule; and (b) by way of presenting research, Dickson's own work on (I) the time-evolution, indeterministic in general, of the extra values that modal interpretations assign to their preferred quantities; (II) the classification of various modal interpretations' choice of preferred quantity, in terms of Dickson's notion of a faux-Boolean algebra.

Part Two, 'Quantum non-locality', comprising Chapters 6 to 9, is the heart of the book. It has two main themes. First, the discussions of Part One, especially of interpretations (i) to (iii), are used to illustrate and justify the general view above, and to argue for more specific claims (see below). Second, Dickson rejects the usual framework for discussing Bell's theorem for the EPR-Bohm experiment. He has three main complaints. (I): Restricting consideration to two times, one 'at or just after emission of the particle-pair from the source' and the other 'at or just before measurement', is too idealized: it prevents one applying genuinely dynamical conditions of determinism and locality to the experiment. (II): The customary distinction between outcome and parameter dependence is without physical significance, since outcomes of an experiment, in any physically relevant sense, incorporate the quantity (parameter) being measured. (III): As a result of (II) and of Dickson's general view above, the widespread view that quantum theory's outcome, but not parameter, dependence represents some kind of quantum holism, but not superluminal causation, is wrong. Dickson of course gives arguments for these rejections; but I should add that they are bound to remain controversial, and indeed have already been controverted in print.

But Dickson combines these two themes in constructive and thought-provoking ways. As a first item of business, his Chapter 7 answers the challenge implicit in (I)—it develops dynamical (i.e. continuous time) conditions of determinism and locality applicable

to the EPR-Bohm experiment. Then the rest of the book deploys the resulting framework, yielding various claims. Two examples must suffice. First, Dickson can prove in terms of these conditions an analogue of the customary result that in the presence of strict correlations, a factorizable stochastic model of the experiment must be deterministic. Since the strict correlations are no accident but arise from theoretically central conservation principles, Dickson concludes that any model that is local must be deterministic (p.145 for non-dynamical models, p. 162 for dynamical ones)—contrary to the folk wisdom that Bell's theorem has refuted local deterministic models. Second, Dickson assesses the various interpretations, especially (i) to (iii), in terms of his determinism and locality conditions. Contraposing the conclusion just reached, indeterministic interpretations must be non-local; and as one would expect, they are non-local in various different ways. More surprising (and again contrary to the folk wisdom) is Dickson's verdict that a deterministic interpretation, viz. the pilot-wave theory, might be local (Chapter 9.4.1). The idea is that the pilot-wave theory avoids Bell inequalities, not through non-locality, but because (thanks to the determinism) the initial configurations (the positions of the particles) have a functional dependence on the later apparatus settings.

Finally, two points of criticism. First, Dickson's aim—to set out the issues that are of interest to him or on which he has something to say—sometimes skews the discussion so that some notions that are central in setting up, or in addressing, the interpretative problems of quantum theory get introduced *en passant* while discussing some very specific matter: examples are the notions of improper mixture and decoherence. Second, the reader should be warned that there are a number of misprints and minor errors, such as missing or misplaced constants in equations. But to sum up: here is an excellent, albeit controversial book.