This book examines in detail two of the fundamental questions raised by quantum mechanics. Is the world indeterministic? Are there connections between spatially separated objects?

In the first part of the book after outlining the formalism of quantum mechanics and introducing the measurement problem, the author examines several interpretations, focusing on how each proposes to solve the measurement problem and on how each treats probability. In the second part, the author argues that there can be non-trivial relationships between probability (specifically, determinism and indeterminism) and non-locality in an interpretation of quantum mechanics. The author then reexamines some of the interpretations of part one of the book in the light of this argument, and considers how they fare with regard to locality and Lorentz invariance. One of the important lessons that comes out of this discussion is that any examination of locality, and of the relationship between quantum mechanics and the theory of relativity, should be undertaken in the context of a detailed interpretation of quantum mechanics.

The book will appeal to anyone with an interest in the interpretation of quantum mechanics, including researchers in the philosophy of physics and theoretical physics, as well as graduate students in those fields.

Quantum chance and non-locality

Probability and non-locality in the interpretations of quantum mechanics

Quantum chance and non-locality

Probability and non-locality in the interpretations of quantum mechanics

W. Michael Dickson
Indiana University

CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK
40 West 20th Street, New York NY 10011–4211, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain
Dock House, The Waterfront, Cape Town 8001, South Africa

http://www.cambridge.org

First published 1998
First paperback edition 2005

Typeset in 10pt Monotype Times

A catalogue record for this book is available from the British Library

Library of Congress cataloguing in publication data

Dickson, William Michael, 1968–
Quantum chance and non-locality : probability and non-locality in
the interpretations of quantum mechanics / W. Michael Dickson.
p. cm.
Includes bibliographical references and index.
ISBN 0 521 58127 3 hardback
1. Quantum theory. 2. Physics–Philosophy.
3. Determinism (Philosophy). 4. Chance. I. Title.
QC174.12.D53 1998
530.12–dc21 97-8813 CIP

ISBN 0 521 58127 3 hardback
ISBN 0 521 61947 5 paperback

to my parents

Cambridge University Press
0521619475 - Quantum Chance and Non-Locality: Probability and Non-Locality in the Interpretations of Quantum Mechanics
W. Michael Dickson
Frontmatter
More information

Contents

Cambridge University Press
0521619475 - Quantum Chance and Non-Locality: Probability and Non-Locality in the Interpretations of Quantum Mechanics
W. Michael Dickson
Frontmatter
More information

Cambridge University Press
0521619475 - Quantum Chance and Non-Locality: Probability and Non-Locality in the Interpretations of Quantum Mechanics
W. Michael Dickson
Frontmatter
More information

Cambridge University Press
0521619475 - Quantum Chance and Non-Locality: Probability and Non-Locality in the Interpretations of Quantum Mechanics
W. Michael Dickson
Frontmatter
More information

Preface

There is a kind of science of everyday phenomena at which we are all experts. We can all predict what will happen when gasoline is thrown on the fire, or when a rock is thrown at the window. None of us is surprised when heated water boils, or when cooled water freezes. These everyday scientific facts come easily.

This everyday science is readily extended to the laboratory, where we learn, for example, that sodium burns yellow, or that liquid helium is very cold. With work, we can learn more complicated facts, involving delicate equipment, and complicated procedures. The result is a kind of science of laboratory phenomena, not different in kind from the science of everyday phenomena.

But what about quantum mechanics? It is, purportedly at least, not about phenomena of the sort mentioned thus far. It is, purportedly at least, not about bunsen burners and cathode ray tubes and laboratory procedures, but about much smaller things — protons, electrons, photons, and so on. What is the relation between the science of quantum mechanics and the science of everyday phenomena, or even the science of laboratory phenomena?

It is no part of my aim to answer this question. However, it will be helpful to note some possibilities. One possibility is that, despite appearances, quantum mechanics really is just about bunsen burners and cathode ray tubes and the like. Perhaps Niels Bohr took such an attitude. (I do not pretend to understand what Bohr wrote, but his name is a convenient label.) He apparently supposed that pieces of laboratory equipment — and everyday objects too — are *outside* the explanatory reach of quantum mechanics. On this reading of Bohr, quantum mechanics does not explain the behavior of these objects in terms of 'quantum objects', but instead describes them *directly*. That is, it describes the relations among them and the results of procedures performed with or on them. On this reading of Bohr, quantum mechanics is just a mathematically sophisticated science of laboratory (and everyday) objects.

But what about protons, electrons, and photons? Are pieces of laboratory equipment not made up of them? Does quantum mechanics not describe their behavior too? Bohr must deny such claims. Instead, he must suppose that terms such as 'proton' do not mean what they seem to mean. The positivists of the first half of this century expended much effort trying to make such a view plausible. They argued that such 'theoretical terms' as 'proton', 'electron', and 'photon' are to be understood as referring not to tiny particles, but to clusters of observations. What quantum mechanics *really* asserts when it says 'a photon is located at the place x' is just a set of sentences each of which can be verified by direct observation. (Such sentences are called 'observation-sentences'.) An example of such a sentence is: 'if a photographic plate is placed at x, then the plate will show a bright spot'.

The positivists' program of reinterpreting the theoretical terms of science has, by most accounts, failed. There does not seem to be any way to make plausible the claim that when quantum mechanics says 'there is a photon at the place x', it *really* means to assert some set of observation-sentences. This failure seems to carry Bohr down with it: there does not seem to be any way to make plausible the claim that, despite appearances, quantum mechanics is *really* only about pieces of laboratory equipment and everyday objects. Quantum mechanics is, it seems, not a science of laboratory objects, but a science of very much smaller things.

Van Fraassen takes a less positivistic view.[1] He says that, at least as far as the *meaning* of the theory is concerned, the relation between quantum mechanics and the science of laboratory objects is just what one would think: quantum mechanics is a theory about very small objects (call them 'quantum objects'); laboratory objects are made of quantum objects; and therefore, quantum mechanics is the basis of our science of laboratory objects. For example, quantum mechanics purports to tell us about how protons, electrons, and neutrons behave. Quantum mechanics says that sodium is made of these. Therefore, quantum mechanics purports to tell us how sodium behaves, for example, when it is burned.

For van Fraassen, then, the theoretical terms of quantum mechanics mean what they appear to mean. When quantum mechanics says 'there is a photon at the place x', it means what it says. But for van Fraassen, we are not to *believe* everything that quantum mechanics says. 'I wish merely to be agnostic about the existence of the unobservable aspects of the world described by science', he writes.[2] Hence, although quantum mechanics does make claims that go behind the phenomena, we are not to follow it that far. We ought not to believe that quantum mechanics is telling us how things really are behind the phenomena of laboratory and everyday objects. Instead, we ought to believe that quantum mechanics provides a (more or less) good model of how those phenomena come about — quantum mechanics tells a good story about why sodium burns yellow, but it is just a story.

One can of course go further, following the classical realist: quantum mechanics means what it says, and moreover what it says is (more or less) the truth. The classical realist claims, therefore, that quantum mechanics goes behind the phenomena, and indeed tells us just how things really are behind the phenomena. Sodium burns yellow because it really is made of protons and electrons and neutrons, which behave in a certain way.

Although much could be said about the relative merits of these positions, the concern here is not with which of them we should adopt, but with their application to quantum mechanics. For that purpose, we may ignore the differences between van Fraassen's view and the classical realist's view, and begin with what they have in common: an agreement that quantum mechanics describes the world of our experience in terms of a 'subphenomenal' world, the world of quantum objects. To put it differently, quantum mechanics grounds our effective science of laboratory and everyday objects in terms of a (more) fundamental science of quantum objects.

If quantum mechanics were clearly successful at describing the world of our experience in terms of unobservable objects such as protons, then there would be little need for much of contemporary philosophy of physics. However, quantum mechanics is not thus successful. I do not mean that quantum mechanics is not successful at all. As a science of laboratory objects it is magnificent. (Of course, there remain problems internal to the theory. For example, nobody has a completely satisfactory way of describing gravitational forces in quantum mechanics, but in general, the theory works very well as a science of laboratory objects.) If you want to know what will happen when you shine a laser beam at a polarizer, consult quantum mechanics. If we could only believe that Bohr and the positivists were right, then we could leave it at that. Quantum mechanics could be seen as the best science of laboratory devices that we have had to date.

However, granting that the positivistic view of quantum mechanics is implausible, we must face up to the fact that quantum mechanics has a very difficult time grounding our science of laboratory objects in terms of a science of quantum objects. The problem can be put in many forms — and in chapter 1 the problem will be stated precisely — but one is this way: in order for quantum mechanics to derive the behavior of laboratory objects from the behavior of quantum objects, it must already take the behavior of the laboratory objects for granted. For example, quantum mechanics in its usual form must take for granted that large objects are situated in fairly well-defined regions of space. (The cup is on the table; the train is in the station; and so on.) However, if the science of quantum objects is fundamental, and the science of laboratory objects is derived, then presumably we want the properties of laboratory objects (or, at least, our beliefs about them) to be derived from the properties of quantum objects, rather than to be taken as given. As it stands, quantum mechanics can correctly answer the question ‘What are laboratory objects like?’ only if we *tell* it the answer. Exactly where quantum mechanics goes wrong will be made clear in chapter 1.

The task of ‘interpreting’ quantum mechanics, then, is to show how quantum mechanics provides a theory of quantum objects that is capable of grounding our science of laboratory and everyday objects, without taking any part of that science for granted.

In general, it is difficult to say whether a proposed interpretation (of which there are many) succeeds. For example, it is not clear just what we should take the phenomena to be. Must an interpretation predict that the Eiffel Tower really does have a fairly definite location, or need it only predict that whenever one looks for the Eiffel Tower, one will find it to be in a fairly definite location? Or is it acceptable to predict merely that people will *believe* that the Eiffel Tower has a definite location? And must people agree about what its location is, or need they merely believe themselves to agree? One’s answers to these questions will depend on what one takes the phenomena of everyday and laboratory objects to be. Different interpretations commit to different accounts of what the phenomena are, and readers may find some interpretations to be more plausible than others for this reason.

However, my aim is not to consider all existing interpretations, much less to evaluate them. Instead, my aim is to use a few interpretations as instruments with which to investigate some questions about quantum objects and their relation to laboratory and everyday objects. More specifically, this book is concerned with probability and non-locality at the level of the quantum objects. Do quantum objects behave deterministically in some sense? Indeterministically? Are there (‘non-local’) connections among widely separated quantum objects? How do these features of quantum objects relate to features of laboratory and everyday objects, or to our beliefs about them? As soon as we recognize that quantum mechanics goes *behind* the phenomena, we may recognize as reasonable the possibility that the quantum-mechanical world is radically different from the phenomenal world, and the relation between them becomes an open question.

Indeed, it is not clear that the question was ever properly closed, though it was, due to the whims of history, foreclosed. After briefly reviewing some of the mathematics of quantum mechanics — quantum probability theory — in a way that is as free of interpretive assumptions as I can make it, and after saying something about what the problem of interpreting quantum mechanics is, I will turn to a time prior to this foreclosure, when the orthodox view (due largely to Bohr) had not yet been forged. For example, Born was eventually the champion of indeterminism, but much earlier, in the same breath that he introduced probabilities to quantum mechanics, he also recognized the serious possibility of a fundamental determinism. This brief lesson from history will open up some possibilities for interpretation.

In the rest of part 1 (chapters 2–5) I consider some of these possibilities as they are found in some existing interpretations. In part 2 (chapters 6–9), I raise questions about locality. First, in chapters 6 and 7, I try to get a handle on just what kinds of 'locality' there are, what kinds are important, and how they are related to determinism and indeterminism. In chapter 8, I consider what conclusions one might draw from the failure of the locality conditions of chapters 6 and 7. In chapter 9, I return to the interpretations of part 1 in the light of the discussion of chapters 6, 7, and 8.

In many ways, the two parts of the book are somewhat independent. However, one of the underlying themes of the book is that questions about determinism and (especially) locality are best addressed in the context of a well-defined interpretation of quantum mechanics. Abstract analysis (such as can be found in chapters 6–8) can go only so far in helping one to understand non-locality, and then the concrete physical details of a given interpretation become important. This point comes to the fore in chapter 9, where we will see that different interpretations answer questions about locality differently.

Although this book does not pretend to be a popular account, I have tried to make it as accessible as possible, given the nature of the topic. For much of the material, readers will need to know very little quantum mechanics or mathematics. Most of the proofs of the theorems that I present in the text have already been published elsewhere in easily available journals, and I have therefore not repeated the proofs here.[3] Short proofs of minor results sometimes appear in the text or in the endnotes. I have also relegated most of the scholarly comments (acknowledgements, hedges, references, and so on) to endnotes, where they are more at home anyway.

Giving thanks, however, is not a scholarly comment; it is good manners, and a pleasure besides. The investigation as given here would have been far less adequate had it not been for the help of many people. I am grateful to them for useful discussions about the foundations of quantum mechanics and thoughtful comments on my work. In particular, I thank David Albert, Jeeva Anandan, Frank Arntzenius, Guido Bacciagaluppi, Jeff Barrett, Joseph Berkowitz, Rob Brosnan, Harvey Brown, Jeffrey Bub, Tim Budden, Jeremy Butterfield, Rob Clifton, Diarmuid Crowley, Eric Curiel, Dennis Dieks, Matthew Donald, Andrew Elby, Michael Friedman, Judy Hammett, Richard Healey, Geoffrey Hellman, Meir Hemmo, R.I.G. Hughes, Jon Jarrett, Martin Jones, J.B. Kennedy, Andrew Lenard, David Malament, James Mattingly, Fred Muller, Phillip Pearle, Itamar Pitowsky, Michael Redhead, Nick Reeder, Simon Saunders, Howard Stein, Charles Twardy, Pieter Vermaas, and Linda Wessels. No doubt there are others I should thank as well, and to them I apologize for my faulty memory. I am also grateful for comments from audiences willing to put up with my half-baked ideas at Bielefeld (Quantum Theory Without Observers), the University of Cambridge, Cleveland (Philosophy of Science Association meeting, 1996), Drexel University (Workshop on the Classical Limit), Indiana University, the University of Minnesota (Workshop on the Quantum Measurement Problem), New Orleans (Philosophy of Science Association meeting, 1994), the University of Notre Dame, the University of Oxford, and the University of Utrecht (Conference on the Modal Interpretation). Material support I was happy and grateful to receive from the University of Notre Dame, the Mellon Foundation for the Humanities, and the International Center for Theoretical Physics. I am especially grateful to Michael Friedman and Indiana University for supporting a year of research that was essential to finishing the book. I owe thanks and much more to Michael Redhead and Jeremy Butterfield for inviting me for an extended visit to the University of Cambridge. The people there have a lot to do with whatever is good about this book. I also owe a special gratitude to James Cushing, who commented extensively on early drafts, and whose role in turning my barely formed thoughts into coherent ideas cannot be overemphasized. Finally, I thank my wife, Misty, who somehow put up with me for measure-one of the time.

Indiana University *M. Dickson*

Acknowledgement

Some parts of the this book were adapted from earlier publications, and I am grateful to the publishers for permission to use that material here. Parts of section 2.3 first appeared in *Foundations of Physics* as Dickson (1994b). Parts of section 4.2.5 first appeared in *Philosophy of Science* as Dickson (1996b). Parts of section 5.2.2 first appeared in *Studies in History and Philosophy of Modern Physics* as Dickson (1996c). Various parts of chapters 6 and 7 first appeared in *Synthese* as Dickson (1996a). Parts of section 9.4.1 first appeared in *Bohmian Mechanics and Quantum Theory: An Appraisal* as Dickson (1996d).