The concept of quantum physics led Einstein to state that 'God does not play dice'. The difficulty he, and others, had with quantum physics was the great conceptual leap it requires us to make from our conventional ways of thinking about the physical world. Rae's introductory exploration into this area has been hailed as a 'masterpiece of clarity' and is an engaging guide to the theories on offer.

This new edition has been revised throughout to take account of developments in this field over the past fifteen years, including the idea of 'consistent histories' to which a completely new chapter is devoted.

Quantum physics
Illusion or reality?

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Illusion or Reality?

Second Edition

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To Ann

I like relativity and quantum theories
Because I don't understand them
And they make me feel as if space shifted
About like a swan that can't settle
Refusing to sit still and be measured
And as if the atom were an impulsive thing
Always changing its mind.

D. H. Lawrence

Time present and time past
Are both perhaps present in time future
And time future contained in time past.

T. S. Eliot

Do you think the things people make fools of themselves about are any less real and true than the things they behave sensibly about?

Bernard Shaw

Contents

Preface to the first edition

Quantum physics is the theory that underlies nearly all our current understanding of the physical universe. Since its invention some sixty years ago the scope of quantum theory has expanded to the point where the behaviour of subatomic particles, the properties of the atomic nucleus and the structure and properties of molecules and solids are all successfully described in quantum terms. Yet, ever since its beginning, quantum theory has been haunted by conceptual and philosophical problems which have made it hard to understand and difficult to accept.

As a student of physics some twenty-five years ago, one of the prime fascinations of the subject to me was the great conceptual leap quantum physics required us to make from our conventional ways of thinking about the physical world. As students we puzzled over this, encouraged to some extent by our teachers who were nevertheless more concerned to train us how to apply quantum ideas to the understanding of physical phenomena. At that time it was difficult to find books on the conceptual aspects of the subject – or at least any that discussed the problems in a reasonably accessible way. Some twenty years later when I had the opportunity of teaching quantum mechanics to undergraduate students, I tried to include some references to the conceptual aspects of the subject and, although there was by then a quite extensive literature, much of this was still rather technical and difficult for the non-specialist. With experience I have become convinced that it is possible to explain the conceptual problems of quantum physics without requiring either a thorough understanding of the wide areas of physics to which quantum theory has been applied or a great competence in the mathematical techniques that professionals find so useful. This book is my attempt to achieve this aim.

The first four chapters of the book set out the fundamental ideas of quantum physics and describe the two main conceptual problems: non-locality, which means that different parts of a quantum system appear to influence each other even when they are a long way apart and even although there is no known interaction between them, and the 'measurement problem', which arises from the idea that quantum systems possess properties only when these are measured, although there is apparently nothing outside quantum physics to make the

measurement. The later chapters describe the various solutions that have been proposed for these problems. Each of these in some way challenges our conventional view of the physical world and many of their implications are far-reaching and almost incredible. There is still no generally accepted consensus in this area and the final chapter summarises the various points of view and sets out my personal position.

I should like to thank everyone who has helped me in the writing of this book. In particular Simon Capelin, Colin Gough and Chris Isham all read an early draft and offered many useful constructive criticisms. I was greatly stimulated by discussions with the audience of a class I gave under the auspices of the extra-mural department of the University of Birmingham, and I am particularly grateful for their suggestions on how to clarify the discussion of Bell's theorem in Chapter 3. I should also like to offer particular thanks to Judy Astle who typed the manuscript and was patient and helpful with many changes and revisions.

1986

Preface to the second edition

My aims in preparing this second edition have been to simplify and clarify the discussion, wherever this could be done without diluting the content, and to update the text in the light of developments during the last 17 years. The discussion of non-locality and particularly the Bell inequalities in Chapter 3 is an example of both of these. The proof of Bell's theorem has been considerably simplified, without, I believe, damaging its validity, and reference is made to a number of important experiments performed during the last decade of the twentieth century. I am grateful to Lev Vaidman for drawing my attention to the unfairness of some of my criticisms of the 'many worlds' interpretation, and to him and Simon Saunders for their attempts to lead me to an understanding of how the problem of probabilities is addressed in this context. Chapter 6 has been largely rewritten in the light of these, but I am sure that neither of the above will wholeheartedly agree with my conclusions.

Chapter 7 has been revised to include an account of the influential spontaneous-collapse model developed by G. C. Ghiradi, A. Rimini and T. Weber. Significant recent experimental work in this area is also reviewed. There has been considerable progress on the understanding of irreversibility, which is discussed in Chapters 8, 9 and 10. Chapter 9, which emphasised ideas current in the 1980s, has been left largely alone, but the new Chapter 10 deals with developments since then.

This edition has been greatly improved by the input of Chris Timpson, who has read and criticised the manuscript with the eye of a professional philosopher: he should recognise many of his suggested redrafts in the text. I gratefully acknowledge useful discussions with the speakers and other participants at the annual UK conferences on the foundations of physics – in particular Euan Squires whose death in 1996 deprived the foundations-of-physics community of an incisive critical mind and many of us of a good friend. At the editing stage, incisive constructive criticism from Susan Parkinson greatly improved the text. Of course, any remaining errors and mistakes are entirely my responsibility.

2004