Heisenberg and the Interpretation of Quantum Mechanics

Werner Heisenberg was a pivotal figure in the development of quantum mechanics in the 1920s, and also one of its most insightful interpreters. Together with Bohr, Heisenberg forged what is commonly known as the 'Copenhagen interpretation'. Yet Heisenberg's philosophical viewpoint did not remain fixed over time, and his interpretation of quantum mechanics differed in several crucial respects from Bohr's. This book traces the development of Heisenberg's philosophy of quantum mechanics, beginning with his positivism of the mid-1920s, through his neo-Kantian reading of Bohr in the 1930s, and culminating with his 'linguistic turn' in the 1940s and 1950s. It focuses on the nature of this transformation in Heisenberg's thought and its wider philosophical context, which have up until now not received the attention they deserve. This new perspective on Heisenberg's interpretation of quantum mechanics will interest researchers and graduate students in the history and philosophy of twentieth-century physics.

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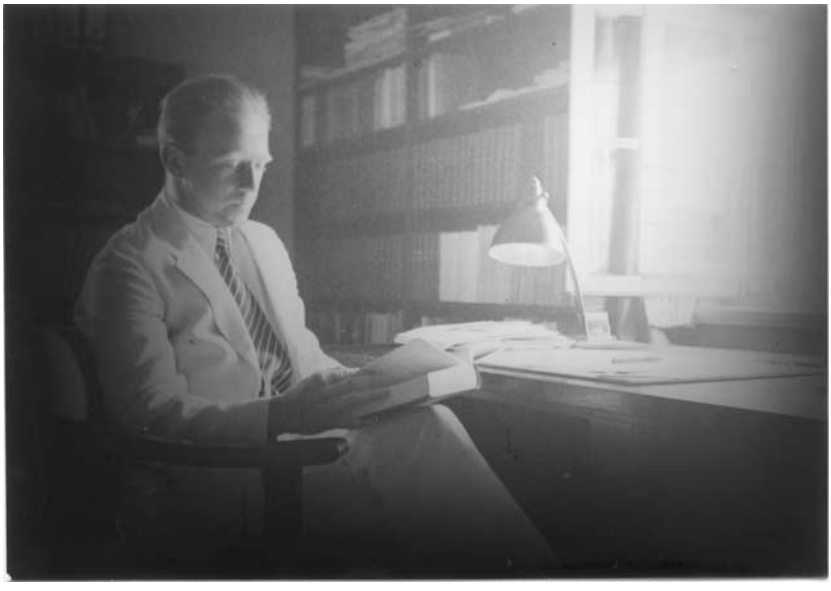

Werner Heisenberg (*Werner-Heisenberg-Archiv*, Munich). Reproduced with the permission of H. Rechenberg.

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The Physicist as Philosopher

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CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Delhi

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521884846

First published 2009

Printed in the United Kingdom at the University Press, Cambridge

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

Library of Congress Cataloguing in Publication data
Camilleri, Kristian.
Werner Heisenberg and the interpretation of quantum mechanics / Kristian Camilleri.
p. cm.
Includes bibliographical references and index.
1. Heisenberg, Werner, 1901–1976 – Philosophy. 2. Physics – Philosophy. 3. Quantum theory. I. Title.
QC16.H395.C34 2008
530.12–dc22
2008034113

ISBN 978-0-521-88484-6 hardback

To my parents, Rita and Joseph

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Preface

When I began work on my doctoral dissertation my aim was not to embark on a historical study of Heisenberg's philosophical thought, but rather to investigate the concept of indeterminacy in quantum mechanics. My intention initially was to begin the thesis with an introductory chapter focusing on the writings of Bohr and Heisenberg, whose discussions in Copenhagen in 1926–7 formed the basis for what would later become known as the 'Copenhagen Interpretation' of quantum mechanics.

However, as I became more closely acquainted with Heisenberg's interpretation of quantum mechanics, I became more intrigued by his philosophical viewpoint. I quickly arrived at the conclusion that what little had been written on the subject had not really done justice to the depth or originality of Heisenberg's interpretation of quantum mechanics. Indeed, much of the secondary literature tended to dismiss him as a positivist, or portray him in his later years as adopting some form of neo-Platonism. What I found particularly striking about the existing secondary literature was the absence of any discussion of Heisenberg's relationship to Kant's philosophy and his emphasis on the constitutive dimension of language, in spite of the fact that both of these are recurring themes in his later writings. A more detailed study of Heisenberg's philosophy of quantum mechanics therefore appeared to me as valuable from both a historical and a philosophical perspective.

It was with this in mind that I subsequently decided to make Heisenberg's philosophical viewpoint the central focus of my thesis. In 2005, I completed my doctoral dissertation entitled 'Heisenberg and Quantum Mechanics: The Evolution of a Philosophy of Nature'. Encouraged by one of my examiners, Professor Don Howard, and my colleagues at the University of Melbourne, I subsequently undertook the task of turning the dissertation into a book. This work is the product of that effort. The ideas contained in Heisenberg's seminal paper on matrix mechanics in 1925 mark the beginning not only of a new phase

in modern physics, but also of Heisenberg's own philosophical journey. This book examines that journey as it unfolded between 1925 and the late 1950s by situating Heisenberg's philosophy of quantum mechanics within the context of various strands of thought in the German-speaking world at the time.

Heisenberg's early inclination towards positivism in the 1920s bears the decisive influence of Einstein's theory of relativity. Yet, by the late 1920s, Heisenberg's thought had moved away from the empiricist viewpoint that had underpinned his early philosophy of quantum mechanics. The nature and scope of this transformation, which forms the central theme of this book, has, up until now, been poorly understood and often completely neglected. Instrumental in this regard were Heisenberg's discussions with Bohr in Copenhagen in 1927. The recognition of the indispensability of classical concepts forms the point of departure for much of Heisenberg's later thought, which brought him into contact with the attempts in the German-speaking world of the 1930s to unravel the basic problem of Kantian epistemology. Increasingly, Heisenberg saw the problem of reality in quantum mechanics under the aegis of a philosophy of language, according to which concepts of classical physics are accorded a priori status insofar as they are the conditions for the possibility of objective experience in spite of their limited applicability. The concept of an object existing in space and time is for Heisenberg an idealisation, but one which remains indispensable for the objectivity of knowledge. By the 1950s, Heisenberg argued that quantum mechanics describes a world of possibilities and potentialities, which paradoxically cannot be regarded as 'objectively real' in any ordinary sense of the term.

While Bohr exerted perhaps the most important philosophical influence on Heisenberg, their intellectual relationship was characterised by hidden disagreements and misunderstandings. This is most strikingly displayed in their respective views on wave–particle duality and complementarity. While Heisenberg certainly used terms such as 'complementarity' and 'wave–particle duality' in his writings, a close reading reveals that these terms had very different meanings for the two physicists. In bringing to light these divergences between Bohr and Heisenberg, this book lends further weight to the view that what is commonly referred to as the Copenhagen interpretation of quantum mechanics comprises a number of different viewpoints and philosophical positions.

A book of this scope and kind is not possible without the support, assistance and encouragement of many people. My primary thanks go to my doctoral supervisor, Dr Keith Hutchison, whose comments and criticism were invaluable in writing the original thesis. I am also indebted to Professor Don Howard, with whom I had many stimulating conversations about the work during my time as Visiting Fellow at the Center for Science, Technology and Values at

the University of Notre Dame in 2007. I owe a debt of gratitude to Dr Vera Butler and Dr Gerhard Wiesenfeldt for their assistance in translating several difficult passages from German into English. While acknowledging their assistance, I take full responsibility for any inaccuracies of translation that appear in this book. Thanks must also go to Edward Hare, who helped with references and citations in the final stages of the preparation of the manuscript.

On a personal note, I would also like to extend my thanks to Giovanna Bartolo for her kind hospitality during May of 2004, in allowing me to work virtually uninterrupted on the thesis, during my stay at her property in Elphinstone. I would also like to thank Howard Sankey, Kelly Farrell, and my parents Joseph and Rita Camilleri for their continual encouragement and helpful comments after proofreading through drafts of the chapters. Without them I have no doubt this book would never have been written. I would also like to acknowledge the contribution made by my friends Costandinos Khtorides, Dr Stephen Ames and Sergio Mariscal, whose intellectual stimulation and encouragement I greatly appreciated during the time of writing the thesis. I would also like to extend my thanks to the anonymous reviewers of the proposal I submitted to Cambridge University Press for their constructive comments as well as the referees of the papers I submitted for publication based on chapters of my original dissertation. Their comments and criticisms have been crucial in revising and rewriting certain sections of the book.

The material from the Hans Reichenbach Collection contained in the *Archives of Scientific Philosophy* has been quoted with the permission of the University of Pittsburgh. I am also grateful to the Special Collections staff at the Ballieu Library at the University of Melbourne for granting me access and permission to quote extensively from the *Archive for the History of Quantum Physics*, which has proved to be an invaluable resource for this work.

A substantial portion of this book derives from papers that have already appeared, although most of the chapters were revised before becoming part of the book. I would therefore like to thank Elsevier, Taylor and Francis and MIT Press for granting me permission to reproduce the material which appears in those chapters. Here is the list of the papers.

- Chapter 4 is based on 'Heisenberg and the Wave–Particle Duality', *Studies in the History and Philosophy of Modern Physics*, 37 (2006), pp. 298–315. Reprinted by permission of Elsevier.
- Chapter 5 is a slightly modified version of 'Indeterminacy and the Limits of Classical Concepts: The Turning Point in Heisenberg's Thought'. *Perspectives on Science*, 15 (2) (2007), pp. 176–99. Reprinted by permission of MIT Press.

- Chapter 6 is an extended and revised version of 'Heisenberg, Bohr and the Divergent Viewpoints of Complementarity'. *Studies in the History and Philosophy of Modern Physics*, 38 (3) (2007), pp. 514–28. Reprinted by permission of Elsevier.
- Chapter 7 is based on 'Heisenberg and the Transformation of Kantian Philosophy', *International Studies in the Philosophy of Science*, 19(3) (2005), pp. 271–87. Reprinted by permission of Taylor and Francis.

I have employed the following abbreviations in the references throughout the book:

ASP = Archive for Scientific Philosophy
AHQP = Archive for the History of Quantum Physics
BSC = Bohr's Scientific Correspondence