THE MEANING OF THE WAVE FUNCTION

At the heart of quantum mechanics lies the wave function, a powerful but mysterious mathematical object which has been a hot topic of debate from its earliest stages. Covering much of the recent debate and providing a comprehensive and critical review of competing approaches, this ambitious text provides new, decisive proof of the reality of the wave function. Aiming to make sense of the wave function in quantum mechanics and find the ontological content of the theory, this book explores new ontological interpretations of the wave function in terms of random discontinuous motion of particles. Finally, the book investigates whether the suggested quantum ontology is complete in solving the measurement problem and if it should be revised in the relativistic domain. A timely addition to the literature on the foundations of quantum mechanics, this book is of value to students and researchers with an interest in the philosophy of physics.

SHAN GAO is Professor of Philosophy at the Research Center for Philosophy of Science and Technology, Shanxi University, and Visiting Professor at the University of Chinese Academy of Sciences. He is the founder and managing editor of the *International Journal of Quantum Foundations*. He is the author of several books and the editor of the recent anthology *Protective Measurement and Quantum Reality: Towards a New Understanding of Quantum Mechanics* (Cambridge University Press, 2015). His research focuses on the philosophy of physics, especially the foundations of quantum mechanics. He also has interests in the philosophy of mind and the philosophy of science.

A thoughtful survey of the many issues arising from the question: does the quantum mechanical wave function represent physical reality? Gao's book will provoke stimulating discussions among physicists and philosophers of science.

Stephen L. Adler,
Institute for Advanced Study, Princeton

A profound book for a deep question.

Nicolas Gisin,
University of Geneva

Gao's admirable book is the first to present a comprehensive analysis of the meaning of the wave function. Drawing upon recent thinking, the author presents a readable up-to-the-minute assessment of the various viewpoints on the significance of the wave function. The book provides an excellent introduction to this key area in the foundations of physics.

Peter Holland,
University of Oxford

This book discusses in great detail the fundamental problem of the conceptual and philosophical status of the quantum wave function. The remarkable depth and completeness of the analysis and the appreciable and objective way of the author in discussing divergent positions render the book a useful tool of investigation. I unrestrictedly recommend this work to all people interested in contributing to clarify the most intriguing aspects of the measurement problem and the various obscure and debated aspects of quantum mechanics.

GianCarlo Ghirardi,
University of Trieste and *ICTP Trieste*

The reality or unreality of the quantum wave function is a topic of lively debate in the foundations of quantum mechanics. In this thoughtful and thought-provoking book, Shan Gao offers nothing less than a novel realist interpretation of the wave function, as describing the propensities of particles undergoing random discontinuous motion. It is a book that everyone interested in the ongoing debates will want to take a look at.

Wayne Myrvold,
Western University

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In Search of the Ontology of Quantum Mechanics

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Shanxi University

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This book is dedicated to Erwin Schrödinger, who introduced the wave function, discovered the equation named after him, and had been attempting to find the ontology of quantum mechanics for the rest of his life.

Erwin with his psi can do
Calculations quite a few.
But one thing has not been seen:
Just what does psi really mean?

– Erich Hückel, translated by Felix Bloch

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Preface

The meaning of the wave function has been a hot topic of debate since the early days of quantum mechanics. Recent years have witnessed a growing interest in this long-standing question.[1] Is the wave function ontic, directly representing a state of reality, or epistemic, merely representing a state of (incomplete) knowledge, or something else? If the wave function is not ontic, then what, if any, is the underlying state of reality? If the wave function is indeed ontic, then exactly what physical state does it represent?

In this book, I aim to make sense of the wave function in quantum mechanics and find the ontological content of the theory. The book can be divided into three parts. The first part addresses the question of the nature of the wave function (Chapters 1–5). After giving a comprehensive and critical review of the competing views of the wave function, I present a new argument for the ontic view in terms of protective measurements. In addition, I also analyze the origin of the wave function by deriving the free Schrödinger equation. The second part analyzes the ontological meaning of the wave function (Chapters 6 and 7). I propose a new ontological interpretation of the wave function in terms of random discontinuous motion of particles, and give two main arguments supporting this interpretation. The third part investigates whether the suggested quantum ontology is complete in accounting for our definite experience and whether it needs to be revised in the relativistic domain (Chapters 8 and 9).

The idea of random discontinuous motion of particles came to my mind when I was a postgraduate at the Institute of Electronics, Chinese Academy of Sciences, in 1993. I am happy that finally it has a more logical and satisfying formulation in this book. During the past 20 years, I have benefited from interactions and discussions with many physicists and philosophers of physics who care about the way the world really is. They are: Steve Adler, Guido Bacciagaluppi, Jeremy Butterfield, Tian Yu

[1] See, e.g., Pusey, Barrett, and Rudolph (2012), Ney and Albert (2013), and Gao (2014a, 2015b).

Cao, Ze-Xian Cao, Eli Cohen, Lajos Diósi, Bernard d'Espagnat, Arthur Fine, Shelly Goldstein, Guang-Can Guo, Bob Griffiths, Richard Healey, Basil Hiley, Jenann Ismael, Adrian Kent, Vincent Lam, Tony Leggett, Matt Leifer, Peter Lewis, Chuang Liu, Owen Maroney, David Miller, Wayne Myrvold, Philip Pearle, Roger Penrose, Huw Price, Matt Pusey, Alastair Rae, Dean Rickles, Max Schlosshauer, Abner Shimony, Lee Smolin, Antoine Suarez, Hans Westman, Ken Wharton, Ling-An Wu, Jos Uffink, Lev Vaidman, and H. Dieter Zeh, among others. I thank them all deeply.

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Finally, I am deeply indebted to my parents, Qingfeng Gao and Lihua Zhao, my wife, Huixia, and my daughter, Ruiqi, for their unflagging love and support; this book would have been simply impossible without them. Moreover, they have never let me forget the true values of life.

[2] See www.ijqf.org for more information about the workshops.