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0521839114 - Pauli's Exclusion Principle: The Origin and Validation of a Scientific Principle
Michela Massimi
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Pauli's Exclusion Principle
The Origin and Validation of a Scientific Principle

There is hardly another principle in physics with wider scope of applicability and more far-reaching consequences than Pauli's exclusion principle. This book explores the origin of the principle in the atomic spectroscopy of the early 1920s, its subsequent embedding into the emerging quantum mechanics, and the later experimental validation with the development of quantum chromodynamics and parastatistics.

The origin of the exclusion principle in 1924 is intertwined with the discovery of the electron's spin, which marked the crisis of the old quantum theory and the transition to quantum mechanics. The reconstruction of this crucial historical episode provides an excellent foil to reconsider Thomas Kuhn's view on incommensurability. In this book, Michela Massimi defends the prospective rationality of this revolutionary transition by focussing on the specific way in which Pauli's principle emerged as a phenomenological rule 'deduced' from some anomalous phenomena and theoretical assumptions of the old quantum theory. The process of validation, which took place in the following decades and transformed Pauli's rule into an important scientific principle, is analysed from both historical and philosophical points of view. A suitable version of 'dynamic Kantianism' is proposed as the philosophical framework for an understanding of the role and function of the exclusion principle.

This historico-philosophical investigation touches upon some of the most relevant issues in philosophy of science and suggests new answers. The variety of themes skilfully woven together makes this book of interest to philosophers, historians, physicists and those with an interest in philosophy working in the natural and social sciences.

MICHELA MASSIMI is a Research Fellow at Girton College, University of Cambridge, affiliated with the Department of History and Philosophy of Science. She gained her *Laurea* in Philosophy at the University of Rome 'La Sapienza' in 1997. Her *Laurea* thesis on the Bohr–Einstein debate on the completeness of quantum mechanics won the Prize of the Accademia Nazionale delle Scienze, detta dei XL in 1998. She gained an M.Phil./Ph.D. from the London School of Economics following research in fields including history and philosophy of science, epistemology, scientific methods and the history of quantum mechanics.

Dr Massimi has lectured on philosophy of science and philosophy of physics courses at the University of Cambridge, at the Philosophy Faculty and at the Physics Department, Cavendish Laboratory. From October 2005 she is Lecturer in History and Philosophy of Science at the Department of Science and Technology Studies of University College London.

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Note on Translation

Most of the historical sources quoted in this book are written in German, and in most cases no English translation is available. Thus the translations in English are my own, unless otherwise indicated in the footnotes.

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Preface

This book is the result of almost ten years of research. It has accompanied me through an intense period of my life, from the end of my undergraduate studies in Rome across the years of my Ph.D. in London until my current Research Fellowship at Girton College (University of Cambridge, UK). I have grown with it, and with it, I have come to develop my philosophical ideas. Looking back, I can see the way they have evolved and focussed; how they came to be refined, and sometimes revised. I owe intellectual debts to many people who in various ways have contributed to the development of my ideas over this span.

My original intention of studying the exclusion principle dates back to 1996. At that time I was an undergraduate student in Rome, very keen on philosophy of science and history of modern physics. Reading Pauli's scientific correspondence, I was struck by a passage of a letter to Landé in which the famous exclusion principle was introduced as an 'extremely natural rule'. It may have appeared 'extremely natural' to Pauli, but to me the overall manoeuvre seemed mysterious and intriguing. I could not help plunging into the details of this fascinating historical episode. I owe an old debt to my teachers Silvano Tagliagambe, who hooked me on philosophy of science, and Sandro Petruccioli, who encouraged me to consider Wolfgang Pauli as a possible research topic.

During the stimulating years of my Ph.D. at the London School of Economics, my research project received a new twist. It became clear how the history of the exclusion principle was intertwined with some crucial philosophical issues, such as the nature of scientific principles, the rationality of theory-choice, the underdetermination of theory by evidence as well as more specific topics in philosophy of physics such as the spin–statistics theorem. I am very grateful to my Ph.D. supervisor, Michael Redhead, who introduced me to philosophy of physics and encouraged me

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to work on the history of the proof of the spin–statistics theorem. Our many discussions together, his help and patient guidance during these years have been crucial for an understanding of the issues presented here. Sections 4.6–4.9 are developed from our joint article 'Weinberg's proof of the spin–statistics theorem', *Studies in History and Philosophy of Modern Physics* **34** (2003), 621–50 (Copyright (2003) by Elsevier. Reprinted with kind permission from Elsevier). I am very grateful also to my Ph.D. co-supervisor Carl Hoefer: his constructive and friendly criticism helped me clarify some philosophical points and better articulate my views.

The staff of the Science Museum Library in London showed great patience in dealing with my request for microfilms from the Archive for the History of Quantum Physics. I would like to thank also the Department of Philosophy, Logic and Scientific Method at the LSE as well as the Arts and Humanities Research Board (AHRB) for financial support during the years of my Ph.D.

This book builds upon my Ph.D. thesis, yet it has ended up being quite different and distinct from it. The past three years at Cambridge have been most fruitful and inspiring for refining my philosophical view. I thank first and foremost Girton College for the three-year Research Fellowship, without which this book would not have been written. Together with the Department of History and Philosophy of Science (University of Cambridge), Girton College has been a stimulating cultural environment for the presentation and discussion of my ideas.

Many philosophers, through their writings and discussions, have influenced my views. Steven French offered most valuable comments on my Ph.D. thesis that were crucial for working it up into book form. The several discussions we had about the exclusion principle and related issues have greatly influenced some of the ideas put forward in this book. There is another person who in the past three years has played an important maieutic role in refining my views, and he is Peter Lipton. His insightful comments on earlier versions of some chapters of this book have been most helpful in clarifying my exposition and suggesting possible ways of developing my arguments. John Norton's articles on demonstrative induction originally inspired my Ph.D. thesis: I thank him for illuminating comments on a paper of mine, 'What demonstrative induction can do against the threat of underdetermination: Bohr, Heisenberg, and Pauli on spectroscopic anomalies (1921–24)', *Synthese* **140** (2004), 243–77 (Copyright (2004) by Kluwer Academic Publishers. Reprinted with kind permission from Springer Science and Business Media), which – in an adapted and shortened form – features in this book as Section 3.3.1. Section 5.3.2.1 is

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a shortened version of my article 'Non-defensible middle ground for experimental realism: we are justified to believe in colored quarks' *Philosophy of Science* **71** (2004), 36–60 (Copyright (2004) by the Philosophy of Science Association. Reprinted with kind permission from the Philosophy of Science Association). I owe also a debt to Marina Frasca-Spada, for comments on an earlier version of Chapter 1 and for initially suggesting the reading of Michael Friedman's *The Dynamics of Reason*. The immense pleasure I took in reading Friedman's book prompted me to rethink some of the main points of my Ph.D. thesis in a refreshingly new way. The reading of Gerd Buchdahl's *Metaphysics and the Philosophy of Science* disclosed a new fascinating perspective for me to explore. I owe the greatest intellectual debt to these two books for the link between a Kantian perspective and the exclusion principle that I have endeavoured to investigate.

I am also grateful to Tian Yu Cao for much helpful advice. Special thanks to Mark Sprevak for innumerable helpful discussions on several points covered in this book, and for much needed support and encouragement during the long and laborious process of writing.

I owe a very special thank you to Stephen Adler, not only for illuminating comments and bibliographic references on the theoretical development of quantum chromodynamics, but also for reading the entire manuscript and for detailed, constructive comments on it. I cannot stress enough how many details Stephen Adler has contributed. Without his invaluable and extremely generous help, I never would have succeeded in attaining the modest level of understanding of quantum chromodynamics presented in Chapter 5. Elie Zahar offered thought-provoking comments on Chapters 1 and 2, for which I am particularly grateful. My Girtonian fellow and friend Peter Sparks commented extensively on the entire manuscript, and very generously gave me assistance with the proofreading. I cannot detail the innumerable improvements he brought to the text, and how much I valued his help. I thank the staff of the Godfrey Lowell Cabot Science Library at Harvard for kindly permitting the inter-library loan of Kuhn's videotape on 'The crisis of the old quantum theory: 1922–25'.

Intellectual debts aside, I owe the major debt to my parents. Their constant encouragement, care, and immense love have always sustained me. 'Thanks' is not the word. This book is dedicated to them, with unspeakable gratitude and love.

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When Galileo rolled balls of a weight chosen by himself down an inclined plane ... a light dawned on all those who study nature. They comprehended that reason has insight only into what it itself produces according to its own design; that it must take the lead with principles for its judgements according to constant laws and compel nature to answer its questions, rather than letting nature guide its movements by keeping reason, as it were, in leading-strings; for otherwise accidental observations ... can never connect up into a necessary law, which is yet what reason seeks and requires. Reason, in order to be taught by nature, must approach nature with its principles in one hand ... and, in the other hand, the experiments thought out in accordance with these principles – yet in order to be instructed by nature not like a pupil, who has recited to him whatever the teacher wants to say, but like an appointed judge who compels witnesses to answer the questions he puts to them ... This is how natural science was first brought to the secure course of a science after groping about for so many centuries.

Immanuel Kant
Critique of Pure Reason, Preface to the second edition, B xiii–xiv

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