# PHYSICAL SYSTEMS

# BOSTON STUDIES IN THE PHILOSOPHY OF SCIENCE



VOLUME 264

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## Conceptual Pathways between Flat Space-time and Matter

*by*

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Springer

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ISSN 0068-0346
ISBN 978-94-007-2372-6 e-ISBN 978-94-007-2373-3
DOI 10.1007/978-94-007-2373-3
Springer Dordrecht Heidelberg London New York

Library of Congress Control Number: 2011938244

*This book is dedicated to my parents,*
Ilana *and* Naaman.

# Preface

This book originates with the first course I took in graduate school. The course was in the Philosophy of Science, and it was taught by Arthur Fine at Northwestern University. It was not the first time I have read Kuhn's *The Structure of Scientific Revolutions*, but this time reading it I became intrigued with Kuhn's claim that the concept of mass is a primary example of a concept that has undergone a scientific revolution. According to Kuhn, the parameter $m$ in Newtonian physics and in the Special Theory of Relativity might be referred to with the same word, mass. However, in fact, the mass concepts in the two theories operate within radically different paradigms, to the extent that they share no meaning and are incommensurable. Kuhn's view struck me as absurd, and I set out to refute him in a short seminar paper. To refute the incommensurability thesis, I tried to articulate what I took to be the overlap in meaning between Newtonian and relativistic mass. The task turned out to be more challenging than I originally thought, but I did come up with a vague account of the shared geometric-dynamic role that mass has in the two theories. It slowly dawned on me that my interpretation of mass deviates from the way in which mass was presented in physics textbook, and so I conceived the idea to write a dissertation on the concept of mass, which will make precise the account vaguely conceived for the seminar paper. I soon found myself reading and thinking about the nature of spacetime, since the semi-geometric interpretation of mass required an analysis of the foundations of spacetime, or at least a decent understanding of the philosophical debates about the topic. While preparing for my project, I began reading seventeenth and eighteenth century texts surrounding the publication of Newton's *Principia*, a reading that took off in its own direction, since I realized that knowing the rich history of Newtonian concepts is key to understanding the various subtle roles that mass originally had for Newton's physics and philosophy of science. Reading into the history and pre-history of Newton's physics also reshaped my project, since I now believed that central to understanding the concept of mass (and physical concepts in general) is the notion of physical system. Inspired by seventeenth century physics, I articulated a philosophical account of physical systems, which takes motion to be a fundamental entity, and systems to be structures in which the motion of composite systems are constructed out of motions of their parts.

The dissertation I ended up writing comprised of a strange mix of historical and philosophical analyses of the foundations of spacetime and mass in both the contexts of Newton's theory and the Special Theory of Relativity. The project, given its peculiar history, ended up touching on various topics in the history and philosophy of physics, from the philosophy of space and time, to the concept of mass, to the scientific method. The concept of mass was like a tied knot at the center of Newtonian physics and the Special Theory of Relativity. Untying this knot required a slow and careful process of disentangling various threads, until the foundation of Newtonian and relativistic physics came into view. (Or, at least what I hope is a novel way of viewing the foundations of classical theories.) Unwinding each thread required the tackling of thorny conceptual problems.

After completing the dissertation, I realized the many infelicities of the work I came up with. I was unhappy with the vague articulation of the connection between spacetime geometry and mass, and took upon myself to articulate my views of spacetime more clearly, beginning with the simplest of axioms that take uniform unidirectional motions to be the fundamental entities of spacetime, and proceeding to derive the known Galilean Spacetime and flat relativistic spacetime. I ended up rewriting most chapters, adding some that were not in the original project, and revising the rest to sharpen the views and make the arguments more cogent.

The project now lies in its final form. It no doubt reflects my peculiar way of thinking and idiosyncratic combination of historical and philosophical inclinations. But I hope the project would be of use to philosophers of physics, who might be interested in the notion of physical system (Chapter 1), the foundations of spacetime (Chapters 2 and 3), my semi-geometric interpretation of the concept of mass (Chapter 6) and the foundations of the Special Theory of Relativity (Chapter 8). The work might also be of interest to philosophers and metaphysicians who are interested in the metaphysics of time (Chapter 4), to historians of physics working on Newton's physics (Chapters 5 and 7), and to philosophers of science and epistemologists interested in scientific methodology (Chapters 2, 7 and 8).

I would like to express my ocean-deep gratitude to Arthur Fine, who made this project possible on many levels, professional and personal. As my dissertation advisor, Arthur provided the bulk of intellectual freedom, institutional support and personal encouragement I needed to conceive, write, rewrite, and complete the project. I would also like to thank the Faculty Research Committee at the University of Richmond for providing financial support during the summers of 2005, 2006, 2008 and 2009 which aided in completing various parts of the project. Gratitude is owed to my colleagues at the philosophy department at the University of Richmond, Geoff Goddu, David Lefkowitz, Miriam McCormick, Del McWhorter, Nancy Schauber and Gary Shapiro, who provided a congenial and supportive intellectual environment in the last 5 years. I benefited tremendously from conversations with and comments from Marc Lange, Andrea Woody, Geoff Goddu, Brannon McDaniel, Miriam McCormick, Wayne Myrvold, Bill Harper, Nick Huggett, Amit Hagar,

Eric Schliesser, Andrew Janiak, Sona Gosh, Kevin Scharp, Natan Berber, Ken Chung, Rob DiSalle, John Norton, Amy Au, Gideon Freudental, Craig Callender, Ed Slowic, and Paul Teller. Last but not least I would like to express my appreciation and gratitude for Michele Bedsaul's help in copy editing the manuscript and preparing it for publication.

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