Fundamental Theories of Physics

Volume 184

The international monograph series "Fundamental Theories of Physics" aims to stretch the boundaries of mainstream physics by clarifying and developing the theoretical and conceptual framework of physics and by applying it to a wide range of interdisciplinary scientific fields. Original contributions in well-established fields such as Quantum Physics, Relativity Theory, Cosmology, Quantum Field Theory, Statistical Mechanics and Nonlinear Dynamics are welcome. The series also provides a forum for non-conventional approaches to these fields. Publications should present new and promising ideas, with prospects for their further development, and carefully show how they connect to conventional views of the topic. Although the aim of this series is to go beyond established mainstream physics, a high profile and open-minded Editorial Board will evaluate all contributions carefully to ensure a high scientific standard.

More information about this series at http://www.springer.com/series/6001

Michael J.W. Hall · Marcel Reginatto

Ensembles on Configuration Space

Classical, Quantum, and Beyond

Springer

Michael J.W. Hall
Centre for Quantum Dynamics
Griffith University
Brisbane, QLD
Australia

Marcel Reginatto
Physikalisch-Technische Bundesanstalt
Braunschweig
Germany

ISSN 0168-1222 ISSN 2365-6425 (electronic)
Fundamental Theories of Physics
ISBN 978-3-319-34164-4 ISBN 978-3-319-34166-8 (eBook)
DOI 10.1007/978-3-319-34166-8

Library of Congress Control Number: 2016940101

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland

This book is dedicated to Robyn, and Mila and Aldo

Preface

Much effort in theoretical physics goes towards building mathematical models that can describe as a wide a variety of physical systems as possible. To build such models, it is necessary to introduce just the right amount of formalism: the mathematics must be able to capture the essential properties of the physical system, while keeping the amount of mathematical structure which does not have a direct physical interpretation to a minimum.

This book is concerned with the description of physical systems in terms of *ensembles on configuration space*. As will be seen, this is an approach which introduces very few physical and mathematical assumptions. As a consequence, the formalism has wide applicability: it can be used to describe physical systems that are deterministic as well as systems subject to uncertainty; discrete systems, particles, and field theories; classical and quantum theories. It also allows for theories that are difficult to formulate using other approaches, such as hybrid quantum-classical theories where there is an interaction between quantum and classical sectors, including the coupling of quantum matter to classical gravity. Finally, it provides insights into classical and quantum physics that not only lead to unified approaches to concepts such as thermodynamics, weak values, locality and superselection, but to novel reconstructions of quantum theory from physical and geometric axioms.

We therefore believe that a detailed account of the formalism and the physics of ensembles on configuration space is valuable in providing a useful (and beautiful) reformulation of existing theories, and in suggesting various generalisations and directions for formulating new theories, and hope that ideas from this book will be incorporated into the standard toolkit of theoretical physicists.

The book is structured into four main parts. Part I deals with general concepts and properties of ensembles on configuration space. Part II examines how quantum mechanics emerges naturally from three very different axiomatic scenarios, based respectively on an exact uncertainty principle, information geometry on configuration space, and local representations of rotations on discrete configuration spaces. Part III develops a theory of hybrid quantum-classical interactions, which overcomes various no-go theorems in the literature and provides an explicit model of interaction between quantum systems and classical measuring apparatuses. Finally, Part IV extends these ideas to show how quantum fields can be consistently coupled to classical gravity. While much of the material is based on publications by the authors and colleagues over the past 15 years or so, many results are presented here for the first time.

The authors would like to thank a number of people and organisations. We began our collaboration on the physics of ensembles on configuration space by email correspondence, and worked on two papers together before finally meeting face-to-face in Germany in 2001, courtesy of travel funding provided by the Alexander-von-Humboldt Foundation. Our collaboration continued, and was bolstered by again being able to meet in person at the Perimeter Institute in 2009, courtesy of travel funding for a conference organised by Philip Goyal. In addition to these organisations and individuals, MH would also like to thank Howard Wiseman at the Centre for Quantum Dynamics, for permitting time to be spent on this book project, and wife Robyn and children Conan and Seriden for their support. MR is grateful to Hans-Thomas Elze and Dieter Schuch for invitations to the very stimulating DICE and Symmetries in Science meetings, where some of these results were presented for the first time, and would like to thank Ruth and Ava for putting up with the late nights and long hours. Finally, we thank Angela Lahee at Springer for her support throughout all the stages of preparation of this book.

Brisbane, Australia — Michael J.W. Hall
Braunschweig, Germany — Marcel Reginatto
March 2016

Contents