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Time in Physics

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Preface

We all have an intuitive picture of time. It is shaped by direct experiences such as the slowly moving hand of a clock, which apparently can be observed by everyone and to arbitrary precision. This intuition is reflected by the laws of classical physics, where time takes the role of a global real-valued parameter. However, we know for more than one century that this intuition is inaccurate. Relativity theory told us that time is observer-dependent, and quantum mechanics implies that the time of events cannot be determined arbitrarily precisely.

Curiously, the two big theories, relativity and quantum mechanics, give very different perspectives on the notion of time. In relativity theory, time is an observer-dependent quantity similar to coordinates in space, but in the quantum-mechanical treatment time is looked upon as a global parametric quantity. While position measurements are described in terms of Hermitian operators, there is no such operator for time measurements. Due to these differences, it is far from obvious how to think of time in a way compatible with both of the big theories. One usually calls this the "problem of time in physics".

If our goal is to realise the dream of finding a theory of everything, there appears to be no way that could avoid tackling the problem of time seriously. And on the road towards a solution, one has to go deep into the foundations of physics. One has to question the various concepts that are still based on our everyday intuition of time, such as causality, and reconsider the way these appear in our current physical theories.

The Workshop on Time in Physics held at ETH Zurich in September 2015 brought together around 60 participants with 22 invited talks from speakers with diverse backgrounds, ranging from physics to mathematics, computer science, and philosophy. They were concerned with the different aspects of time in physics, as well as its meaning and interpretations. This included discussions on relations between time and causal structures, entropy, entanglement, the laws of thermodynamics, and cosmology.

In these proceedings, about half of the invited workshop speakers write about their research on the notion of time. They not only provide insight into the state of the art but also shed light on what may be promising directions for further research.

Some of the questions tackled are: Is an arrow of time physical and does it stem from the second law of thermodynamics as usually believed? What does time represent on a cosmological level and can we connect it to entanglement? How are causality and time related, and what can we deduce from causal relations? How intertwined are the notions of free will and time in physics?

This book is aimed at students and scientists learning about the concept of time and related areas. The choice of topics represents different approaches that are currently followed by researchers working in the field. The readers can find answers to questions about time, but more likely they will also find themselves puzzled by the many fundamental questions that are still open. The book may therefore also serve as a starting point for new research into the subject. We would like to thank all the authors for their time and knowledge they shared when writing chapters for this book. We are grateful to the referees whose comments helped shaping the articles to their final form. Our thanks go to Clemens Heine from Birkhäuser Basel for his help and encouragement during the preparation and realisation of this book. We are also thankful to Luca Sidler and the whole editorial team of Birkhäuser for the smooth editing and publishing procedure.

Zurich, Switzerland R. Renner
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