REVERSING THE ARROW OF TIME

'The arrow of time' refers to the curious asymmetry that distinguishes the future from the past. *Reversing the Arrow of Time* argues that there is an intimate link between the symmetries of 'time itself' and time reversal symmetry in physical theories, which has wide-ranging implications for both physics and its philosophy. This link helps to clarify how we can learn about the symmetries of our world, how to understand the relationship between symmetries and what is real, and how to overcome pervasive illusions about the direction of time. Roberts explains the significance of time reversal in a way that intertwines physics and philosophy, to establish what the arrow of time means and how we can come to know it. This book is both mathematically and philosophically rigorous yet remains accessible to advanced undergraduates in physics and the philosophy of physics. This title is also available as Open Access on Cambridge Core.

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What Is in This Book

This is a book about the arrow of time, that curious asymmetry that distinguishes the future from the past. My aim is to answer two philosophical questions: what is the arrow of time, and how can we come to know about it? These questions depend on a remarkable concept of twentieth-century physics called 'time reversal'.

My central thesis is that there is an intimate link between the symmetries of 'time itself' and the concept of time reversal symmetry in our best physical theories, which has wide-ranging implications for both physics and its philosophy. This link helps to clarify how we can learn about the symmetries of our world; how to understand the relationship between symmetries and what's real; and how to overcome pervasive illusions about the direction of time. It also helps to establish a sense in which time has an arrow. I will argue that, although the world is filled with illusory arrows of time, there is still an asymmetry in the structure of time itself, which survives the idealisations of our best scientific theories and which holds independently of the contingent facts about matter and energy. I will explain how to understand what time asymmetry means and how to identify the experimental evidence for it.

To prepare you for the writing style, this work intertwines mathematics, philosophy, and physics, as natural philosophy often does. It would be a mistake to follow some commentators in thinking that 'philosophy' is a synonym for 'speculation'. The philosophy in this book rather consists in a fascination with big questions, together with an insistence on sharp conceptual distinctions and clear, empirically informed thought. This is not a work of popular science: many discussions will assume some understanding of modern philosophy and physics, at about the level of an advanced undergraduate. That said, I have tried to keep things easy-going where

possible and have included a large number of diagrams. Chapter 1 in particular is readable by any audience and includes a compact discussion of some classic philosophy of time as well as a history of time reversal in physics.

Each of the eight chapters states and argues for a separate conclusion, and each chapter can be read independently of the others. However, there is also a single, over-arching proposal that informs every chapter – that the 'structure' of time is linked to the structure of our dynamical theories, in a way that allows one to empirically check whether time itself has an arrow. The core of that proposal is described and argued for in Chapter 2. I then use this perspective in Chapter 3 to try to settle a debate about what time reversal means. Chapter 3 can also be used to guide a general course on the philosophy of physics for advanced undergraduate or master's students: it includes detailed reviews of the structure of classical and quantum mechanics, noting many philosophical debates along the way. Chapter 4 then introduces what 'time reversal symmetry' means and connects it to the philosophy of symmetry more broadly. This chapter can be used to guide an introductory course on symmetry.

Chapter 5 debunks a number of purported 'arrows' that are not true asymmetries of time: in electromagnetism, statistical mechanics, cosmology, quantum theory, and causation. Perhaps the most heterodox claim of the book appears in Chapter 6, where I argue that classical thermodynamics, despite being widely viewed as a paradigmatic example of a time-asymmetric theory, is in fact temporally symmetric in all but a trivial way. This chapter also serves as an introduction to the philosophical foundations of thermodynamics, including a systematic presentation of its geometric structure, which is perhaps not yet widely appreciated by philosophers or physicists.

Finally, in Chapter 7, I argue that time reversal symmetry violation in particle physics provides evidence for an arrow of time itself and explain how it avoids some possible pitfalls. The time asymmetry of electroweak theory is, as far as I can tell, the only compelling experimental evidence for an arrow of time, but it is very compelling indeed. Chapter 8 then turns to the study of other time reversing symmetries like CT (time reversal with charge conjugation) and CPT (charge conjugation plus parity and time reversal) symmetry in relativistic quantum field theory. Here I defend the arrow of time from the claim that it is erased by these more general symmetries. In

particular, I argue against a claim of Richard Feynman that reversing time necessarily exchanges matter and antimatter.

To cover all this ground, I have built on the efforts of many extraordinary philosophers, physicists, and friends. In the few places that I disagree with them, I have tried to meet them half-way. I hope the result is some progress in the physics and philosophy of time.

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