

The Physical Basis of  
The Direction of Time



H.-Dieter Zeh

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**The Direction of Time**

With 20 Figures

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# Preface

This book arose from a series of lectures which I gave at the University of Heidelberg during the summer terms of 1979, 1982 and 1986. They led in 1984 to the publication in German of *Die Physik der Zeitrichtung*, which appeared as Vol. 200 of the Springer Lecture Notes in Physics. The present English version is not merely a translation of these notes, but has been widely revised and extended. The number of changes and additions roughly increases with chapter number. Chaps. 5 and 6 have been completely rewritten (except for Sect. 5.1, which is a revised version of the former §5.2). The new title is intended to express the somewhat more ambitious program of this book as compared to its German predecessor.

My interest in this subject stemmed originally from an attempt to place the quantum mechanical measurement process in its proper relation to other irreversible phenomena. It soon became evident that statistical thermodynamics is too limited for the search for the common roots of the obviously related arrows of time. It is precisely the interconnectedness of many areas of physics, and not least their relation to some fundamental concepts (or perhaps prejudices) of epistemology, which sustained my fascination with the subject of this book over many years. Thus it was not my intention to describe technicalities or mathematical problems, but to point out the essential physical ideas (which are often overlooked). In none of its chapters does the book predominantly address the specialist of the various fields; in fact it is aimed mainly at the student or scientist who is interested in an overview of the whole problem, and who wants to consider his specific field of research in its relation to others. I also hope that the book may be of some interest to the philosopher who is familiar with the concepts of theoretical physics.

My first lecture on this subject as a whole was stimulated by Paul Davies' (1977) book entitled *The Physics of Time Asymmetry*. However, I felt that some of its subjects (for example the thermodynamical arrow of time – Chap. 3 of this book) might deserve a technically more detailed discussion, that the formal relations between the different arrows should be elaborated upon, and in particular that the peculiar role and importance of the quantum measurement process should be further analyzed (Chap. 4). Moreover, our knowledge about the arrow of time that appears in general relativity and cosmology (Chap. 5) has grown enormously since the appearance of Davies' book, partly due to his own contributions. In addition, attempts to under-

stand the problem of the quantization of the spacetime metric, and therefore of time itself, have gained considerable momentum during recent years, and may even turn out to give the whole issue a completely new perspective (Chap. 6). I thus hope that this book is appearing at an appropriate time.

Chapter 1 briefly summarizes my understanding of the physical concept of time. Chap. 2 on the radiation arrow will hardly contain anything that is not generally accepted, except perhaps for the remark that the Wheeler-Feynman absorber condition has to be supplemented by an asymmetric condition in order to characterize absorbers. Chap. 3 on thermodynamics emphasizes the fundamental observer-relatedness of the macroscopic description, which may appear to be in conflict with the objective nature of the thermodynamical concepts. Chap. 4 on the quantum mechanical arrow may be greeted controversially, since I have tried – for good reasons – to present a consistent description that avoids the ‘non-concepts’ of complementarity and dualism used in a fundamental way by the Copenhagen interpretation. Chap. 5 describes the important cosmological aspects of arrows of time and the relations between the concepts of spacetime geometry and thermodynamics that have been discovered during the last two decades as a consequence of combining general relativity and quantum field theory. Finally, Chap. 6 about the quantization of time combines concepts and results from Chaps. 1, 4 and 5.

I am very much indebted to Dr. Erich Joos for his assistance during preparation of the original German version, and to Dr. Claus Kiefer, for corresponding help with the present book. They were both unbelievably patient in correcting several preliminary versions and suggesting improvements. I also wish to thank Dr. M. Stöckler for his very careful reading of the manuscript. Ms. Sonja Bartsch and Ms. Beate Witzler helped me very much by typing an early version for the Macintosh, and Mr. Carl Ulbricht by eliminating some of the most disturbing Germanisms from it. I am particularly glad to acknowledge the assistance of Dr. Angela Lahee in editing the (almost) final version. Mr. K. Mattes performed the translation into  $\text{\TeX}$ .

Heidelberg, February 1989

*H.-D. Zeh*

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