The Physical Basis of The Direction of Time

H. Dieter Zeh

The Physical Basis of
The Direction of Time

Fourth Edition
With 34 Figures

Springer

Professor Dr. H. Dieter Zeh
Institut für Theoretische Physik
Universität Heidelberg
Philosophenweg 19
69120 Heidelberg, Germany

Library of Congress Cataloging-in-Publication Data applied for.

Die Deutsche Bibliothek - CIP-Einheitsaufnahme:
Zeh, Heinz-Dieter:
The physical basis of the direction of time / H. Dieter Zeh. – 4. ed.
ISBN 978-3-540-42081-1 ISBN 978-3-540-38861-6 (eBook)
DOI 10.1007/978-3-540-38861-6

http://www.springer.de

Originally published by Springer-Verlag Berlin Heidelberg New York in 2001

Typesetting: Data conversion by K. Mattes, Heidelberg
Cover design: Erich Kirchner, Heidelberg

Printed on acid-free paper SPIN 10837695 55/3141/ba 5 4 3 2 1 0

Preface to the Fourth Edition

The fourth edition contains again various revisions and updates throughout the whole book. There are many new comments, formulations and arguments, several new references, and three minor error corrections (regarding page 22, 112 and 146 of the third edition).

This time I am grateful to David Atkinson (for a very useful discussion of radiation damping – Sect. 2.3), to Larry Schulman (for comments on the problem of simultaneous arrows of time – Sect. 3.1.2), and to Paul Sheldon (for a discussion of the compatibility of closed time-like curves with quantum theory – Chap. 1). The most efficient help came from John Free, who carefully edited the whole fourth edition (not only for matters of English language).

Heidelberg, April 2001 *H. D. Zeh*

Preface to the Third Edition

The third (1999) edition of the Direction of Time offered far more revisions and additions than the second one in 1992. During the seven years in between, several fields of research related to the arrow of time had shown remarkable progress. For example, decoherence proved to be the most ubiquitous manifestation of the quantum arrow, while articles on various interpretations of quantum theory (many of them with inbuilt time-asymmetric dynamical aspects) can and do now regularly appear in reputed physics journals. Therefore, most parts of Chap. 4 were completely rewritten and some new sections added, while the second part of Chap. 3 was affected by these changes in order to prepare for the discussion of measurements and *dynamical maps* within the framework of classical ensemble theory.

However, *all* parts of the book have been revised, and some of them completely rewritten, whilst essentially maintaining the book's overall structure. Some of the new aspects of the third edition may be listed here:
The Introduction now attempts to distinguish rigorously between those time *asymmetries* which still preserve dynamical determinism, and the various 'irreversiblities' (arrows of time proper) which are the subject of this book.
In Chap. 2, the concept of forks of causality is contrasted to that of forks of indeterminism (to be used in Chaps. 3 and 4), while the treatment of the radiation reaction of a moving charge (Sect. 2.3) had to be updated.
Sects. 3.2–3.4 have been given a new structure, while a discussion of semigroups and their physical meaning has been added to Sect. 3.4.
In Chap. 4, only Sects. 4.1 and 4.5 (the former Sect. 4.3 on exponential decay) are not entirely new. In particular, there is now an extended separate Sect. 4.3 on decoherence. Sects. 4.4 (on quantum dynamical maps) and 4.6 (on the time arrow in various *interpretations* of quantum theory) have been added.
In Chap. 5, the thermodynamics of acceleration is now presented separately (Sect. 5.2), while Sect. 5.3 on the expansion of the universe contains a discussion of the consistency of cosmic two-time boundary conditions. The dynamical interpretation of general relativity with its concept of *intrinsic time* is discussed in Sect. 5.4.
Chap. 6 now covers *various* aspects of quantum cosmology and thus includes, as Sect. 6.1, the material of the former Sect. 5.2.2 on phase transitions of the vacuum with their consequences on entropy capacity. In Sect. 6.2 on quantum gravity, emphasis is on *timelessness*, which is enforced by quantization of a reparametrization invariant theory. There is a new Sect. 6.2.2 on the

emergence of classical time along the lines of the Tomonaga-Schwinger equation, while Sect. 6.2.3 describes some speculations on the impact of quantum cosmology on the concept of black holes and their thermodynamical properties. A numerical toy model has been appended after the Epilog in order to illustrate some typical arguments of statistical mechanics.

I also hope that most disadvantages which had resulted from the fact that I previously had (very unfortunately) translated many parts of the first edition from the German lecture notes that preceded it (Zeh 1984), have now been overcome. Two new books on the arrow of time (Price 1996 and Schulman 1997) have recently appeared. They are both well written, and they discuss many important aspects of 'irreversible' physics in a consistent and illuminating manner – often nicely complementing each other as well as this book. However, I differ from their views in two respects: I regard gravity (not least its quantized form) as basic for the arrow of time, as I try to explain in Chaps. 5 and 6, and I do not think that the problem of quantum measurements can be solved by means of an appropriate final condition in a satisfactory way (see Footnote 4 of Chap. 4).

I wish to thank Julian Barbour, Erich Joos, Claus Kiefer, Joachim Kupsch, York Ramachers, Huw Price, Fritz Rohrlich, Paul Sheldon and Max Tegmark for their comments on early versions of various parts of the manuscript.

Heidelberg, April 1999 *H. D. Zeh*

Contents