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Preface

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The nature of time is one of the problems that has persisted over the centuries, it is still a puzzle today and new aspects of it arise, whenever a new era of physics opens up. The discrepancy between the time symmetry of the fundamental laws of physics and the observed "arrows of time" has fascinated physicists since the late half of the 19-th century.

In classical physics this time asymmetry is expressed by the cosmological arrow, the radiation arrow and the thermodynamic arrow of time. The thermodynamic arrow of time is formulated as an increase in entropy. The cosmological arrow of time and the radiation arrow of time are formulated as boundary conditions of the fundamental dynamical equations.

In quantum physics the dynamical equations, the Schrödinger equation for states and Heisenberg equation for observables, are time symmetric differential equations. One of the quantum mechanical arrows of time is attributed to the wave function collapse and quantum decoherence. It is the analogue of the thermodynamic arrow of time in classical physics. The radiative arrow of time of classical electrodynamics selects from among all possible solutions of Maxwell equations only the retarded solutions i.e. those related to outgoing boundary conditions. In quantum physics there is also an analog of the radiative arrow of time. This arrow of time can also be formulated as time asymmetric boundary condition for the Schrödinger and Heisenberg equations.

Ordinary quantum mechanics, using Hilbert space boundary conditions, always leads to the time symmetric solutions of the dynamical (Schrödinger or Heisenberg) equations. The Hilbert space axiom excludes asymmetric time evolutions. This is in contrast to the fact that many elementary quantum systems exhibit time asymmetric evolution.

Quantum mechanical time asymmetry is most prominently observed in decaying quantum systems. The decay of a quantum mechanical system is an irreversible process. The unstable systems (resonances and decaying states) are characterized by the mass M and the width Γ, or by the lifetime $\tau = \hbar/\Gamma$. Scattering processes with the production of a resonance are described by the Breit-Wigner amplitude

$$\frac{\Gamma/2}{E-(M-i\Gamma/2)}$$

with complex mass $(M - i\Gamma/2)$. The states with complex mass or energy are not permitted in Hilbert space quantum mechanics. An extension of the space of states of quantum mechanics to the rigged Hilbert space (Gel'fand triplet) allows the mathematical definition of the generalized eigenvector of a self adjoint Hamiltonian with complex energy (or complex mass). This Dirac ket with complex eigenvalue $(M - i\Gamma/2)$ describes the unstable Gamow states. The time evolution transformations of the Gamow states are time asymmetric and given by the time evolution semigroup $\exp(-iHt)$ with $0 \leq t < \infty$. In the relativistic theory the states of decaying particles and resonances with complex mass are classified according to the minimally complex irreducible representations of the Poincaré-semigroup transformations in the forward light cone.

In conventional scattering theory the spaces of *in*- and *out*-states are represented by one and the same Hilbert space. On the other hand if one distinguishes between the preparation apparatus and the detector then in the presence of an unstable states one is naturally led to a pair of different spaces, one for the prepared *in*-states and the other for the detected *out*-states. The new hypothesis of the time asymmetric quantum theory chooses for these *in*- and *out*-spaces the spaces of smooth Hardy functions analytic in the lower and upper complex energy plane, respectively. The dual spaces of these Hardy spaces contain the Gamow kets and the time evolution in these spaces is asymmetric.

Other approaches to irreversible processes at the classical level rely on stochastic equations or their "dual" equations. This corresponding description of the quantum irreversibility of open systems with external environment is based on the Markovian time evolutions.

The present issue contains a selection of papers devoted to different subjects ranging from the irreversibility of open quantum systems to time asymmetry of unstable states and resonances. These papers, with the exception of two, were presented at the Sixth Workshop on Time Asymmetric Quantum Theory organized within the XXV International Colloquium on Group Theoretical Methods in Physics held in Cocoyoc, Mexico during 2–6 August 2004. This workshop had been the continuation of the series of the workshops whose proceedings have been published in the International Journal of Theoretical Physics **36** (11), **38** (1), **42** (10) and in Springer Lecture Notes in Physics **504** (1998)and **622** (2003).

The papers contained in this volume can be divided into two categories: 1. description and properties of resonances and unstable states, 2. general quantum mechanical properties of the systems with unstable states. The first category includes the contributions by H. Baumgärtel, A. Bohm, N.L. Harshman, R. de la Madrid and two papers by the group of A. Mondragón. The second category consists of the contributions by W. Blum, L. Boya *et al.*, M. Courbage, K. Gustafson, I. Rotter *et al.*

I hope the reader will enjoy some of the beautiful papers included in this collection and I also hope that the papers of this issue will contribute to a better understanding the quantum time asymmetry.

Piotr Kielanowski
Mexico City, May 2006.