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Preface

The present volume contains a selection of research and review papers presented at the fourth and the fifth Workshop on *Time Asymmetric Quantum Theory*, held in Jaca, Spain in May/June 2001 and at the ICTP in Trieste, Italy in July 2002. Previous workshops on *Time Asymmetric Quantum Theory* took place in Goslar and Clausthal, Germany. This series of workshops had its origin in two workshops that took place at Peyresque, Alpes de Haute-Provence, France, with the titles: *Workshop on Cosmology and Time Asymmetry* (published in *International Journal of Theoretical Physics* **36**(11)) and *Fundamental Aspects of Quantum Mechanics* (published in *International Journal of Theoretical Physics* **38**(1)).

The Workshops IV and V on *Time Asymmetric Quantum Theory* were concerned with resonances and decay phenomena and their mathematical description.

Time asymmetry is one of the features of what one usually calls the arrows-of-time. It is mathematically described by time asymmetric boundary conditions of time symmetric dynamical equations; its most prominent consequence is causality. The radiation arrow-of-time is the best known example from classical physics. The dynamical equations of classical electrodynamics (Maxwell equations) are time symmetric. But in Nature only the retarded solutions are realized. Since there is no axiom in electrodynamics that prevents the choice of the retarded solution, one can add as a new axiom the condition that selects the retarded solutions from among *all possible* solutions (Sommerfeld radiation condition). Another example is the cosmological arrow of time.

Standard quantum theory in Hilbert space cannot be augmented with such a condition for the Schrödinger or the Heisenberg equation, because the Stone–von Neumann theorem inevitably leads to unitary and therewith reversible time evolution.

In the heuristic scattering theory one circumvents this problem by using retarded (and advanced) Green's functions or purely outgoing boundary conditions, which—very much like the retarded (advanced) potentials of classical electrodynamics—contain time asymmetry. With the Green's functions one has admitted distributions into the theory and is outside the Hilbert space. However, Hilbert space boundary conditions and the heuristic notions of resonance scattering and decay are in conflict with each other and this leads to many puzzles and inconsistencies, like deviation from the exponential law versus exponential catastrophe

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or violation of causality. Standard quantum theory can only provide an inexact or fuzzy description of resonance and decay phenomena; time asymmetric quantum theory removes the time-symmetric Hilbert space boundary condition of quantum mechanics and replaces it by an axiom that selects those observables as allowed solutions of the Heisenberg equation that are preceded by the preparation of the state.

Since resonance and decaying states are prominent manifestations of the fundamental quantum mechanical arrow-of-time, a substantial part of the workshops was devoted to the resonance phenomena in atomic and molecular physics, in nuclear physics, and in particle physics. The theoretical explanations employed various mathematical methods and different levels of mathematical rigor.

The heuristic methods based on the Weisskopf–Wigner approximation provide already a description of remarkable accuracy. This method is employed in the papers of Chapter *Resonances: Models and Computations* that apply complex effective Hamiltonians and similar methods.

Since the Gamow states with exponential decay are, like the Dirac kets, singular mathematical objects, the mathematics of distributions and rigged Hilbert spaces is required. To relate the resonance phenomena of scattering experiments with the exponential time-dependence for decay processes one needs a particular kind of rigged Hilbert spaces, given by the spaces of Hardy functions on the complex energy Riemann sheet for the S-matrix. This and related mathematical topics are discussed in the papers of Chapter *Rigged Hilbert Spaces and Related Mathematical Notions*.

The unified theory of resonance scattering and decay, using the mathematics of Hardy spaces, is the subject of papers in Chapter *Time Asymmetric Quantum Theory and Applications*. The papers discuss the nonrelativistic as well the relativistic theory. Forward light-cone asymmetry is the relativistic analogue of time asymmetry.

Chapter *Miscellaneous Related Topics* discusses other methods and topics connected with causality, the arrow-of-time and related subjects.

Chapter *Lectures of General Interest* contains general (evening) lectures for a larger audience. The last paper on history of quantum mechanics expresses a novel point of view. This paper, as well as the ones in preceding chapters, have been refereed by the experts in their fields.

A. Bohm
M. Gadella
P. Kielanowski