QUANTUM DYNAMICS AND INFORMATION

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PREFACE

The 46th Winter School of Theoretical Physics on *"Quantum Dynamics and Information: Theory and Experiment"*, organized by the University of Wrocław and the University of Opole, was held at the heart of Karkonosze Mountains in the Geovita Center in Lądek Zdrój, Poland during the period 8-13 February, 2010. The present volume contains texts of most of invited lectures delivered during the conference and a selected sample of poster presentations.

The central theme of the School was quantum dynamics, regarded mostly as the dynamics of *entanglement* and that of *decoherence*. Both these concepts appear to refer to the dynamical behavior of surprisingly fragile features of quantum systems, finite-dimensional, few and many-body structures, that are supposed to model quantum memories and stand for an arena for quantum data processing routines.

Quantum information theory is a new, dynamically evolving discipline and has many faces. Any experimental realization of a quantum information processing system is widely recognized as a difficult task because of decoherence effects, particularly dephasing, which entail loss of quantum information through randomization of the relative phase of quantum states. One of the important topics in this connection is the concept of quantum entanglement, that might possibly become the basis of a quantum computer theory and ultimate quantum computer exploitation principles.

Entanglement of quantum states is the most nonclassical manifestation of the quantum formalism. It shows up when the system consists of two (or more) subsystems and the global (pure) state cannot be written as a product of the states of individual subsystems. Then, the best knowledge of the whole of a composite system may not include nor reflect a complete knowledge of its subsystems. This notion can be generalized to mixed states, and a mixed state of a quantum system is entangled if the corresponding density matrix cannot be expressed as a convex combination of tensor products of density matrices of its subsystems.

A fundamental nonclassical aspect of entanglement was recognized already in 1935 by Schrödinger who was led to say that it is "not one but rather the characteristic trait of quantum mechanics". In the present-day the theory of entanglement is well established and known to play a central role in the quantum information science, e.g. quantum communication, quantum cryptography and quantum computing.

The entanglement property is not often considered to be a physically (experimentally) accessible property of a quantum system. However, it may stand for a resource that can help in tasks such as the reduction of classical communication complexity, frequency standards improvements and clock synchronization. From the theoretical point of view, the entanglement concept has a very complex structure and the theory of entanglement tries to give answers to a number of questions of primary importance: how to optimally detect the entanglement, how to protect enanglement against degradation (fragility issue), and how to characterize it, control and quantify.

In the context of quantum dynamics, the most important aspect of entanglement is that it is fragile with respect to any noise resulting from an interaction with the environment. This may lead to the dissipation and destruction of correlations and due to that, entanglement may disappear even though it was initially present in the quantum system state. To control a corresponding process of disentanglement, it is important to understand details of the complex nature of the evolution of entanglement in open quantum systems.

In most models of quantum open systems, quantum coherence may be destroyed asymptotically in time, but in some cases entanglement still may abruptly and completely disappear (die out) in finite time. This phenomenon, named *entanglement sudden death* (ESD), has been explored in a variety of contexts: theoretically and experimentally in continuous and discrete systems, few body and many-body systems. Physical systems that have been examined include electrons on the solid state lattice subject to an electromagnetic field, photons in a system of mirrors and beam splitters, atoms confined in cavities. The omnipresent noise can be both classical and quantum in origin.

The entanglement of qubits, which is at the heart of promising speed-up offered by quantum computations, usually enhances the effects of decoherence, and thus causes a faster decay of computational fidelity. Therefore, the study of decoherence as a phenomenon which leads to a corruption of the information stored in the system as well as errors in computational steps is strongly intertwined with the field of quantum information.

The first challenge one has to deal with is the role of quantum correlations and entanglement in the process of decoherence and the description of the robustness of some entangled states under typical environmentally induced decoherence phenomena. The other key problems include engineering ways to modify and eliminate decoherence in applications of quantum information processing by exploiting the so-called decoherence free subspaces, entanglement distillation or dynamical decoupling procedures. On the other hand, contribution to experiments on decoherence to further understand the quantum to classical transition to read out results of quantum computations should take place.

Finally, it should be pointed out that the existing protocols for dynamical dephasing control during all stages of quantum information processing, namely the storage and gate operations, cannot be readily implemented in available experimental set-ups, such as ion traps, quantum dots or optical lattices, and so they require further investigations on both the experimental and theoretical level.

Spontaneous emission in the two-atomic system is an example of the noise which diminishes entanglement and may lead to the entanglement sudden death. On the other hand, the process of photon exchange can induce correlations between atoms which can partially overcome decoherence. As a result, some amount of entanglement present in the system can survive. Moreover, there is a possibility that this process can entangle separable states of two atoms.

Such *dynamical creation of entanglement* in the presence of a noisy environment, have attracted a great deal of attention. In particular, the production of robust asymptotic entanglement for closely separated atoms as well as the existence of transient entanglement in the case of arbitrary separations have been established. In that case, the dynamics of entanglement is so complex that the phenomena of revivals of entanglement that has already been destroyed or even *delayed sudden birth of entanglement* can occur. For general Markovian completely positive dynamics of two atoms immersed in a common bath, dynamical creation of entanglement has been established.

All that is merely a small part of the whole entanglement, decoherence and information intertwine. There exist excellent reviews on some of those topics: quantum entanglement as an information resource, entanglement in many-body systems, information measures and thermodynamically justified processing of information. Grand reviews were published as well on various aspects of decoherence and its possible role for the classical-quantum intertwine.

Most of the related experimental topics that include: single trapped atom manipulations, single atom-photon interaction in a cavity (cavity quantum electrodynamics), advances in large molecules interferometry, interferometry of Bose–Einstein condensation and a multitude of experiments on quantum information transfer (teleportation issue included), have nowadays received ample publications coverage.

That gave us, Editors for this volume, some freedom in slightly reshuffling the accents. While editing the present volume we have intentionally pushed its contributors to present topics that still remain insufficiently explored, albeit being of an utmost importance.

The programme of the School has been shaped with the help of the scientific committee comprising: V.M. Akulin, Ph. Blanchard, S. Chwirot, R. Horodecki, P. Knight, J. Rembieliński, R.F. Werner, A. Zeilinger, P. Zoller and M. Żukowski. We convey our thanks to all of them.

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The Editors
July 2010

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