Dissipation, non-commutative geometry and quantization

Giuseppe Vitiello

Dipartimento di Fisica "E-R.Caianiello" e INFN
Università di Salerno

The study of dissipative systems in quantum theory is of strong theoretical interest and of great relevance in practical applications. As a matter of fact, any microscopic system is always embedded in some macroscopic environment and therefore it is never really isolated. Dissipation effects play a relevant role in high energy physics and in the early universe physics, in the vacuum structure in the presence of gravitational background, as well as in condensed matter physics, in phase transition phenomena, and in general in quantum field theory at non-zero temperature. Also, the squeezed states of light entering quantum optics can be identified, up to elements of the group of automorphisms of SU(1, l), with the states of the damped quantum harmonic oscillator. A major difficulty that appears in the study of dissipative systems in quantum mechanics is that the canonical commutation relations are not preserved by time evolution due just to damping terms. Then one introduces fluctuating forces in order to preserve the quantum mechanical consistency, namely the canonical structure. Another way to handle the problem is to start from the beginning with a Hamiltonian that describes the system, the bath, and the system-bath interaction. Subsequently, one eliminates the bath variables which originate both damping and fluctuations, thus obtaining the reduced density matrix. Some aspects of dissipation in quantum field theory can be studied by starting from the example of the quantum mechanical damped harmonic oscillator. One can show that the set of states of the system splits into unitarily inequivalent representations of the canonical commutation relations. At quantum level the irreversibility of time evolution is expressed as tunneling among the unitarily inequivalent representations. Statistical and thermodynamic properties of the formalism are analyzed and canonical quantization is shown to lead to time dependent SU(1, 1) coherent states, well known in high energy physics as well as in quantum optics and thermal field theory. As a consequence, the doubling of the algebra, realized in terms of Hopf deformed algebra, is intimately related to the gauge structure of the theory. Coherence appears then to be the basic dynamic law, supporting the transition from the micro to macro-physics, the change of cardinality, fractal structures and the emergence of the arrow of time. One can also show that the dissipation term in the Hamiltonian for a couple of classical damped–amplified oscillators manifests itself as a geometric phase and is actually responsible for the appearance of the zero point energy in the quantum spectrum of the 1D linear harmonic oscillator. Moreover, it appears that quantum dissipation induces, in the plane of the forward and backward motions, a noncommutative geometry, as an effect of phase interference, which is closely analogous to the Aharonov–Bohm effect. Indeed one finds that the quantum interference phase between two alternative paths in the plane (as in the Aharonov–

Bohm effect) is determined by the noncommutative length scale and the enclosed area between the paths. This in turn provides the connection between the noncommutative length scale and the zero point fluctuations in the coordinates. The links we establish between noncommutative geometry, quantum dissipation, geometric phases and zero point fluctuations, may open interesting perspectives in many sectors of quantum physics, e.g., in quantum optics and in quantum computing, in theoretical computer science or whenever quantum dissipation cannot be actually neglected in any reasonable approximation. In some aspects, our work has been inspired by ’t Hooft proposal according to which information loss in certain classical systems may lead to “an apparent quantization of the orbits which resembles the quantum structure seen in the real world”. Our work may thus also play a role in the ’t Hooft proposal of the interplay between classical deterministic systems with loss of information and quantum dynamics in view of the established relation in that frame between geometric phase and zero point energy.

Bibliography

SU (1, 1) squeezed states as damped oscillators
E Celeghini, M Rasetti, M Tarlini, G Vitiello,
Modern Physics Letters B 3 (16), 1213-1220, 1989

Squeezing and quantum groups
E Celeghini, M Rasetti, G Vitiello, Physical Review Letters 66 (16), 2056, 1991

Quantum dissipation
E Celeghini, M Rasetti, G Vitiello, Annals of Physics 215 (1), 156-170, 1992

Dissipation and Topologically Massive Gauge Theories in the Pseudo-Euclidean Plane
M. Blasone, E. Graziano, O. K. Pashaev and G. Vitiello
Annals of Physics 252, 115-132 , 1996

Quantum Gravity as a Dissipative Deterministic System,
Gerard 't Hooft, Class. Quant. Grav. 16 3263, 1999

Dissipation and quantization
M Blasone, P Jizba, G Vitiello, Physics Letters A 287 (3-4), 205-210, 2001

Quantum dissipation induced noncommutative geometry
S. Sivasubramanian , Y.N. Srivastava, G. Vitiello, A. Widom
Physics Letters A 311, 97–105, 2003

Links. Relating Different Physical Systems Through the Common QFT Algebraic Structure
G. Vitiello, in Quantum Analogues: From Phase Transitions to Black Holes and Cosmology,
William G. Unruh Ralf Schützhold (Eds.)
Springer-Verlag Berlin Heidelberg, Lect. Notes Phys. 718, 165–205, 2007

Gauge theory and two level systems
A Bruno, A Capolupo, S Kak, G Raimondo, G Vitiello
Modern Physics Letters B 25 (20), 1661-1670, 2011

Noncommutative spectral geometry, algebra doubling, and the seeds of quantization
M Sakellariadou, A Stabile, G Vitiello, Physical Review D 84 (4), 045026, 2011

Quantum Field Theory and Its Macroscopic Manifestations
M. Blasone, P. Jizba, and G. Vitiello, Imperial College, London, England, 2011.

Berry-Like Phase And Gauge Field in Quantum Computing
A.Bruno, A. Capolupo, S. Kak, G. Raimondo, G. Vitiello,
in Systems science, methods, models, simulations and approaches towards a general theory of change, G. Minati, M. Abram, E. Pessa (Eds.), World Scientific, Singapore, 83 - 94, 2012

The Cellular Automaton Interpretation of Quantum Mechanics
Gerard 't Hooft, arXiv:1405.1548 [quant-ph]

... and Kronos ate his sons.
G.Vitiello
in Quantum Physics and Space-time Dynamics Beyond Peaceful Coexistence, ed. by I. Licata, Foreword by G. 't Hooft. Imperial College Press, London, 465-486, 2016

Quantum field theory and coalgebraic logic in theoretical computer science
G. Basti, A. Capolupo, G.Vitiello
Progress in Biophysics and Molecular Biology 130 A, 39-52, 2017

Time, the arrow of time, and Quantum Mechanics,
Gerard 't Hooft, arXiv:1804.01383 (quant-ph).