Irreversible dynamics in quantum mechanics by the introduction of a time scale

The thesis deals mainly with the notion of microsystem and macrosystem in quantum mechanics, with which I have concerned myself during my PhD studies, that have been strongly influenced by the works of Prof. Ludwig on the foundations of quantum mechanics, works which are tentatively compactly surveyed in the first chapter of the thesis. The main effort has been toward the development of a general formalism, inside non relativistic quantum field theory, for the description of the reduced dynamics of slowly varying degrees of freedom. Such a description should be meaningful on a time scale determined by the choice of relevant observables. The introduction of a time scale is necessary in order to neglect quantum correlations and to actually define a system as a part of the world separated from the rest. A finite isolated macrosystem is specified by a separation procedure inside a finite space region and by a time scale, that must be large enough in order to break up the correlations with the environment, replace physical walls by suitable boundary conditions, make actually reliable the microphysical model which is used to describe the local behavior. The propose is to tune the formalism of quantum mechanics to this situation, emphasizing already in the formalism that only coarse grained descriptions make sense: obviously the striving to lower the time scale and to push cutoffs farther still remains, but should not be based only on formal procedures like thermodynamic limit and renormalization.

The formalism has been already developed in detail in the case of a microsystem interacting with a macroscopic system, which can be seen as the simplest perturbation of matter at equilibrium, a first step in the direction of the description of non equilibrium systems. One obtains for the statistical operator describing the microsystem a dynamical semigroup in which the operators determining the structure of the generator, having the Lindblad form, are linked to the T-matrix describing the interaction between the particle and the macroscopic system. The result has been considered in the framework of modern one particle experiments and has been applied to two very different cases, neutron matter interaction near the optical regime and quantum Brownian motion, thus showing the wide range of validity of the obtained expression. In the case of neutron matter interaction particular attention has been devoted to incoherent effects in the dynamics, keeping in mind the recent beautiful neutron interferometry experiments made by the group of Prof. Rauch in Wien. Also possible experimental consequences of our analysis of the contribution to incoherent scattering have been suggested.

This formal approach has been pursued further in order to apply it to macroscopic systems. In this case the reduced dynamics pertains to some degrees of freedom (e.g., distribution function in a kinetic description; densities of mass, energy and momentum in a hydrodynamic description) that are slowly varying on the chosen time scale, much longer than the typical time of microphysical interactions. The obtained equations are formally very similar to those derived for the case of the microsystem, so that a kind of unified description may be envisaged. A first application of these calculations leads to a homogeneous Boltzmann equation with complete quantum statistical corrections (Uehling – Uhlenbeck equation).