A statistical approach to the quantum measurement problem

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Courses of quantum mechanics usually present the properties of ideal measurements as specific postulates which supplement the standard ones. In order to prove these properties and not postulate them, we treat here a measurement as a set of hamiltonian dynamical processes where the tested system S interacts with a macroscopic apparatus A; this implies the use of quantum statistical mechanics. The theory relies on a minimalist formulation of quantum mechanics, where a state, represented by a density operator (or even by a pure state), does not refer to an individual object but to a statistical ensemble in which this object is embedded. The Hamiltonian that governs the evolution of S+A during the measurement should have some specific properties to ensure that the repeated process behaves as an ideal measurement. The expected final state of S+A in a repeated measurement can then be identified, for a large set of runs as well as for arbitrary subsets, as a thermodynamic equilibrium state. The study, in the framework of quantum statistical dynamics, of the relaxation towards such a state exhibits several time scales. A severe difficulty arises, due to a quantum ambiguity: the knowledge of the final state of S+A for the full large set of runs of the measurement does not allow us to identifiy, among the various mathematically allowed candidates, the final states associated with physical subensembles of runs. This specifically quantum difficulty is overcome owing to a special type of relaxation which holds for any subensemble. By relying on the structure of the final states thus found for all possible subensembles of runs, we infer the uniqueness of the outcome of each individual run, providing a solution of the "quantum measurment problem". The "reduction of the state" of S follows, and a frequency interpretation is given to Born's rule.

[1] A. Allahverdyan, R. Balian and Th. Nieuwenhuizen, arXiv:1303.7257

[2] A. Allahverdyan, R. Balian and Th. Nieuwenhuizen, Physics Reports, 525 (2013)