Aspects of Quantum Thermodynamics: Facts, debatable issues and unsolved issues

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Thermodynamics at the macroscopic scale, considered at *weak* system-bath coupling, together with its Statistical Mechanics in thermal equilibrium are well established theories, as developed by pioneers such as Gibbs, Einstein, Boltzmann and others. However, recent activities in the thermodynamics of small mesoscopic and nanoscopic systems require new in-depth investigations, such as the equivalence between different ensembles. Moreover, this is also the case for concepts such as *work* or *heat* when taken away from the quasi-static regime. The issue becomes even more intriguing in a quantum setting, such as when studying fluctuation relations or the operation of quantum heat engines.

The state of the art of this quite active field is plagued by many subtleties, pitfalls and inconsistencies; some of which even apply at manifest thermal equilibrium, especially beyond weak system-bath coupling. A major challenge, both theoretical and experimental, is the invasive nature of quantum measurements due to its unavoidable impact on the measured system. This aspect becomes essential when several measurements are performed on one and the same system, as for example for the measurement of quantum work and quantum heat, both requiring measurements of a properly defined energy at the beginning and at the end of the process in question. Fact then is: if anything can be said at all – it must be said as clearly as possible (Wittgenstein, 1889-1951).

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