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Quantum Causality and the Indefinite Thermodynamic Arrow of Time

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Abstract:

The aim of this thesis was to investigate the consequences of the application of quantum mechanics to the causal relations among events and to the thermodynamic arrow of time. The first part of this thesis concerns three studies falling under the umbrella of 'indefinite causality', that is, the notion according to which the causal structure between events may become genuinely indefinite. In particular, the first work constitutes the first experimental demonstration of the indefinite causality of a process through the measurement of a 'causal witness', i.e., a mathematical object designed to produce a certain outcome whenever a process is not consistent with a well-defined causal order. The second work experimentally demonstrates indefinite causality outside the quantum formalism. The third work looks beyond the concept of indefinite causality, to cover a variety of quantum superpositions of trajectories. The second part of this thesis comprises two studies pertaining to the field of quantum thermodynamics. The linking element between the previous part of this thesis and the present one is rooted in the concept of thermodynamic arrow of time and its directionality. The fourth work of this thesis proposes that quantum mechanics may permit quantum superpositions between thermodynamic processes yielding two opposite entropy variations. Finally, the last study proposes a simple interferometric scheme that enables a direct estimate of the work distribution and of the average work dissipated during an isothermal thermodynamic process. The investigation of indefinite causal structures and of the arrow of time may enable novel quantum information and quantum thermodynamic tasks, and provide methodological tools for future quantum theories of gravity. To this end, proposing and implementing experimental approaches towards these goals, as undertaken in this thesis, may help to lay the groundwork for a deeper understanding of the concept of time and its role in major physical theories.