entropy 2021

Abstract

Quantum Chaos and Quantum Randomness—Paradigms of Quantum Entropy Production †

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† Presented at the Entropy 2021: The Scientific Tool of the 21st Century, 5–7 May 2021; Available online: https://sciforum.net/conference/Entropy2021/.

Published: 5 May 2021

Quantum chaos and quantum measurement have one constitutive feature in common: They capture information at the smallest scales to lift it to macroscopic observability, thus generating classical facts. Fundamental bounds of the information content of closed quantum systems with finite-dimensional Hilbert space restrict their entropy production to a finite timescale. Only in open systems where fresh entropy infiltrates from the environment, quantum dynamics (partially) recovers sustained entropy production as in classical chaos.

This interpretation opens a novel perspective also on randomness in quantum measurement, where a macroscopic apparatus observes a quantum system. Notably in spin measurements, their results involve an element of fundamental unpredictability. The analogy with quantum chaos suggests that random outcomes of quantum measurements could, in a similar manner, reveal the entropy generated through the coupling to a macroscopic environment, which is required anyway to explain a crucial feature of quantum measurement that becomes manifest in the collapse of the wavepacket: decoherence. However, the subsequent step from a set of probabilities to specific individual measurement outcomes (the "second collapse") still evades a proper understanding in terms of microscopic models. Could it be explained by the exchange of entropy between macroscopic apparatus and measured system?

I explore this hypothesis in the case of spin measurements. The model of quantum measurement proposed by Zurek and others is combined with a unitary approach to decoherence using heat baths that comprise only a finite number N of modes, as recently proposed in quantum chemistry and quantum optics. For large N >> 1, the dynamics of the measured spin is expected to exhibit a scenario of episodes of significant spin polarization in either direction of increasing length, alternating with spin flips, determined by the initial condition of the apparatus. I present preliminary analytical and numerical results which support this expectation.