SMALL AND SIMPLE SYSTEMS THAT FAVOR THE ARROW OF TIME

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ABSTRACT

The second law of thermodynamics is the source of the irreversibility that we experience in everyday life. One formulation of this 2nd law states that the entropy of an isolated system increases irreversibly until it reaches its maximum value. Then the entropy stays at this maximum, which stabilizes the thermal equilibrium and helps to define the temperature (T) needed for Boltzmann's factor ($e^{-J/kT}$) to give the probability that a system has energy J. A common claim is that the 2nd law is not microscopic, instead applying only to large and complex systems that are unlikely to return to their initial state, while small and simple systems are routinely reversible. Another claim is that the 2nd law applies only to most initial states, while entropy may decrease from some states (that are extremely rare for large systems). I will present evidence that such claims are false, at least for computer simulations of standard models [1-3]. In other words, we find that the 2nd law of thermodynamics is a fundamental physical law, not just a statistical rule of thumb. I will then speculate about a microscopic mechanism that may provide a common source of irreversibility in nature.

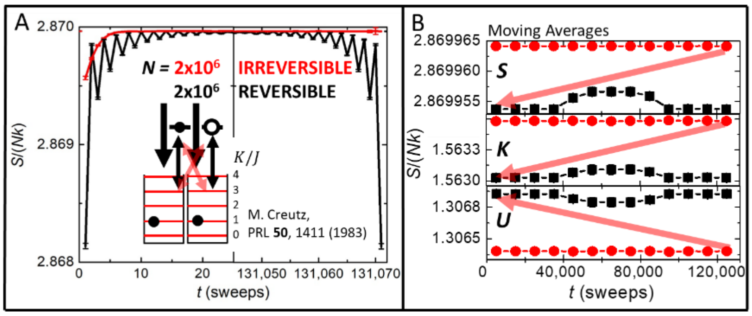

Figure 1. A) Inset: the Creutz model is a closed system that can be as small as two Ising spins coupled to a bath of two Einstein oscillators. Main figure: time-dependent entropies of two large systems having irreversible dynamics (red) or reversible dynamics (black). The dynamics is reversed at the midpoint of each simulation, but (of course) only reversible dynamics shows Loschmidt's paradox for entropy reduction that violates the 2nd law of thermodynamics. B) High-resolution values of the entropies of the spins U, the bath K, and the total S. Arrows show how the onset of reversible dynamics always reduces the total entropy, due to the bath.

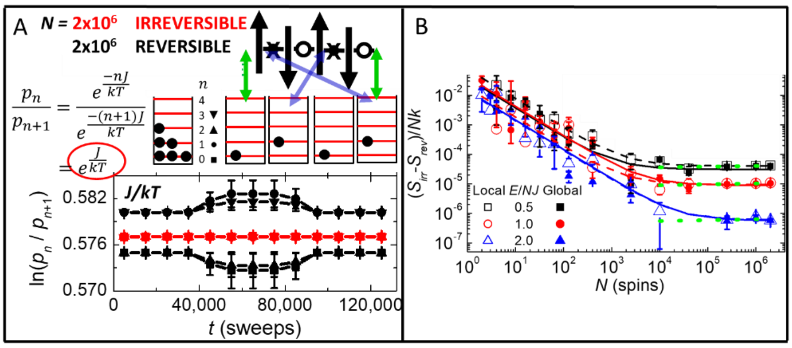

Figure 2. A) Top: the occupation of energy levels in the bath of Einstein oscillators should obey Boltzmann statistics. Bottom: logarithm of the ratio of occupation probabilities yields a well-defined temperature only for irreversible dynamics in large systems. B) Log-log plot of the difference between entropies of irreversible and reversible dynamics as a function of system size.

Keywords: Irreversible thermodynamics, second law, Loschmidt's paradox, statistical fluctuations, Ising model.

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REFERENCES

[1] R. V. Chamberlin, V. Mujica, S. Izvekov, J. P. Larentzos, *Energy localization and excess fluctuations from long-range interactions in equilibrium molecular dynamics*, Physica A **540** (2020), 123228.

[2] R. V. Chamberlin, *Small and simple systems that favor the arrow of time*. Entropy **26** (2024), 190.

[3] R. V. Chamberlin, S. M. Lindsay, *Nanothermodynamics: There's plenty of room on the inside*, Nanomaterials **14** (2024), 1828.