

Frequently Asked Questions

Entropy Has No Direction: Mirror-State Paradox and Constraint-Reshaped Distributions

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This FAQ accompanies the paper:

T. Peng, *Entropy Has No Direction: A Mirror-State Paradox Against Universal Monotonic Entropy Increase and a First-Principles Proof that Constraints Reshape the Entropy Distribution* $P_\infty(S; \lambda)$, arXiv:2602.15369 [cond-mat.stat-mech] (2026).

<https://arxiv.org/abs/2602.15369>

The L^AT_EX source of the manuscript and this FAQ are available at <https://github.com/tpeng1977/entropy>. For the full argument, proofs, and references, see the manuscript `entropy.tex` / `entropy.pdf`.

1. What is the mirror-state paradox?

For any microstate A at time t_0 , define the *mirror state* $B = \mathcal{T}A$ (time reversal: same positions, reversed momenta). Under time-reversal invariant dynamics, the forward evolution of B is the time-reversed past of A . If a *universal* law said “entropy does not decrease” for every microstate and every time, then applied to both A and B it would imply $S_A(t_0 + \delta t) \geq S_A(t_0)$ and $S_A(t_0 - \delta t) \geq S_A(t_0)$ for small $\delta t > 0$. So t_0 is a two-sided local minimum of $S_A(t)$. Since t_0 is arbitrary, every time is a local minimum; with minimal regularity (e.g. continuity of S along trajectories), entropy must be constant on every trajectory. So a universal monotonicity claim is logically incompatible with time-reversal symmetry and would remove any entropic arrow of time.

2. Does this disprove the Second Law of Thermodynamics?

It shows that the Second Law *cannot* be a *universal* fundamental law in the form “entropy does not decrease” (either strict trajectory-wise or as a universal statistical principle) when microscopic dynamics are time-reversal invariant. The paper does not deny that in many practical settings entropy tends to increase; it denies that this follows as a universal, state-by-state consequence of the underlying physics. Any one-way statement about ΔS must rely on additional structure: special initial conditions, coarse-graining, or constraints/boundaries.

3. What replaces “entropy has a direction”?

The consistent view: **entropy has no direction; it is described by a probability distribution $P(S)$** . The shape of this distribution depends on constraints and boundary conditions (encoded as λ). Long-time behavior is captured by $P_\infty(S; \lambda)$, the entropy distribution induced by the invariant measure under those constraints.

4. What is $P_\infty(S; \lambda)$?

$P_\infty(S; \lambda)$ is the *long-time* entropy distribution: the probability distribution of (coarse-grained) entropy S in the limit of long times, under constraint parameters λ (geometry, boundaries, fields, etc.). It is determined by the invariant measure (e.g. microcanonical on the energy shell or canonical with a heat bath). The paper proves from first principles that changing λ (Hamiltonian and/or accessible phase space) changes this distribution.

5. How do constraints reshape the entropy distribution?

Constraints enter via the Hamiltonian $H(\Gamma; \lambda) = H_0(\Gamma) + V_c(\Gamma; \lambda)$ and/or the accessible set $\mathcal{A}(\lambda)$. They change the invariant measure (e.g. uniform on the energy shell in the microcanonical case) and hence the macrostate probabilities $\pi_m^{(E)}(\lambda) = W_m^{(E)}(\lambda)/\Omega(E; \lambda)$. So the induced distribution over entropy values $P_\infty^{(E)}(S; \lambda)$ changes when the accessible macrostate volumes $W_m^{(E)}(\lambda)$ change with λ .

6. When does $P_\infty^{(E)}(S; \lambda)$ stay the same (up to translation)?

Only in one case: when the multiset of accessible macrostate volumes $\{W_m^{(E)}(\lambda)\}$ is scaled by a common factor $c > 0$ (up to permutation). Then $P_\infty^{(E)}(S; \lambda_2)$ is just $P_\infty^{(E)}(S - k_B \ln c; \lambda_1)$. Otherwise the distribution changes *structurally*, not merely by shifting the entropy axis.

7. What does the Qiao–Wang experiment show?

Qiao and Wang showed that in charged small nanopores (effective pore size $d_e \approx 1 \text{ nm}$, ion size $d_i \approx 0.7 \text{ nm}$, so $d_i < d_e < 2d_i$) the steady-state ion distribution is intrinsically out of equilibrium: the potential difference can be nearly an order of magnitude larger than the heat-engine upper bound from the traditional Second Law. The system can produce useful work in an isothermal cycle by absorbing heat from a single thermal reservoir. This is interpreted as the asymmetric constraint (nanopore geometry) reshaping $P_\infty(S; \lambda)$, making spontaneous low-entropy transitions accessible without requiring compensating entropy increase elsewhere.

8. Does this mean a perpetual motion machine of the second kind is possible?

The paper argues that the traditional *fundamental* impossibility of a second-kind perpetual motion machine (extracting work from a single heat reservoir in a cycle) is not a universal consequence of time-reversal invariant physics. In the corrected framework, that “impossibility” is model- and limit-dependent. Together with the Qiao–Wang result, both theoretical and experimental barriers are argued to be overcome, so that practical devices based on constraint-reshaped entropy distributions are in principle feasible. Engineering and scaling remain open.

9. What about heat death?

If entropy does not have a universal direction and constraints can reshape $P_\infty(S; \lambda)$, then a *universal* heat death of the universe is not a necessary consequence of the same first principles. The paper does not make detailed cosmological claims but notes implications for long-term sustainability and the possibility of sustained non-equilibrium phenomena under suitable constraints.

10. Which definition of entropy is used?

Boltzmann (coarse-grained) entropy: a time-reversal symmetric partition of phase space into macrostates $\{C_m\}$, with $S_m^{(E)} = k_B \ln(W_m^{(E)}/W_0)$ on the energy shell. The conclusions depend on this choice only in that the coarse-graining is assumed time-reversal symmetric, $S(\mathcal{T}\Gamma) = S(\Gamma)$.