

# Problem Statement: Uncertainty, Entropy, and Quantum Path Selection

This problem statement outlines a proposed independent research direction by Christian Dzidula Dotsey. The focus is on reinterpreting the uncertainty principle as a microscopic stabilizing mechanism, exploring its possible connection to entropy conservation ( $dS = 0$ ), and investigating whether these ideas relate to quantum path-selection frameworks such as those developed by Krenn and collaborators.

In standard quantum mechanics, the uncertainty principle is formulated as lower bounds on the joint precision of non-commuting observables (e.g.,  $\Delta x \cdot \Delta p \geq \hbar/2$ ,  $\Delta E \cdot \Delta t \geq \hbar/2$ ). Traditionally, this is interpreted as a mathematical constraint on measurement or state preparation, not as an active law of nature. However, uncertainty relations already play a stabilizing role: for instance, they prevent atomic collapse by ensuring that electron confinement leads to large kinetic energy. In thermodynamics and statistical mechanics, equilibrium corresponds to the condition  $dS = 0$ . This suggests a possible link: perhaps uncertainty principles act at the microscopic level as constraints that enforce the macroscopic entropy conservation condition.

Hypothesis: The uncertainty principle can be reinterpreted as a stabilizing law that prevents configurations incompatible with equilibrium or conservation, and this microscopic constraint may underlie the thermodynamic condition  $dS = 0$ . Furthermore, in quantum path frameworks, uncertainty and entropy conditions may jointly govern which paths are realizable, thereby influencing state selection and interference patterns.

## Research Questions:

1. Can uncertainty relations be rigorously connected to entropy conservation laws ( $dS = 0$ )?
2. Do suppressed or forbidden transitions (due to uncertainty) correlate with reduced or divergent entropy production in toy models?
3. How can toy models (particle in a box, two-level systems) reveal connections between  $\Delta E \cdot \Delta t$  and entropy production?
4. Can graph-based path formalisms be extended to include uncertainty/entropy constraints, effectively forbidding certain paths?
5. What experimental observables (e.g., entropy production in mesoscopic systems) would serve as evidence for such suppression effects?

Proposed Methodology: • Phase A – Formalize the hypothesis and map uncertainty relations onto entropy conditions (literature review, analytic sketches). • Phase B – Study toy models (confinement, two-level system with bath) to test how uncertainty relates to entropy production. • Phase C – Implement numerical simulations (e.g., Lindblad master equations) to compute entropy production and test suppression of transitions. • Phase D – Connect results to path/graph formalisms to ask whether suppressed paths correspond to forbidden graph matchings. • Phase E – Compare with experimental entropy production literature to identify measurable consequences.

Selected References: • Coles et al. (2019) – Entropic Energy–Time Uncertainty Relation (PRL). • Krenn, Gu & Zeilinger (2017) – Quantum Experiments and Graphs (PRL). • Goes, Fiore & Landi (2020) – Entropy production in driven-dissipative transitions (PRResearch). • Ptaszyński & Esposito (2023) – Quantum vs classical contributions to entropy production (PRX Quantum). • Aharonov & Bohm (1961) – Time in the Quantum Theory and Energy–Time Uncertainty (PR).