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Bridging quantum mechanics and cosmology: The role of the generalized uncertainty principle

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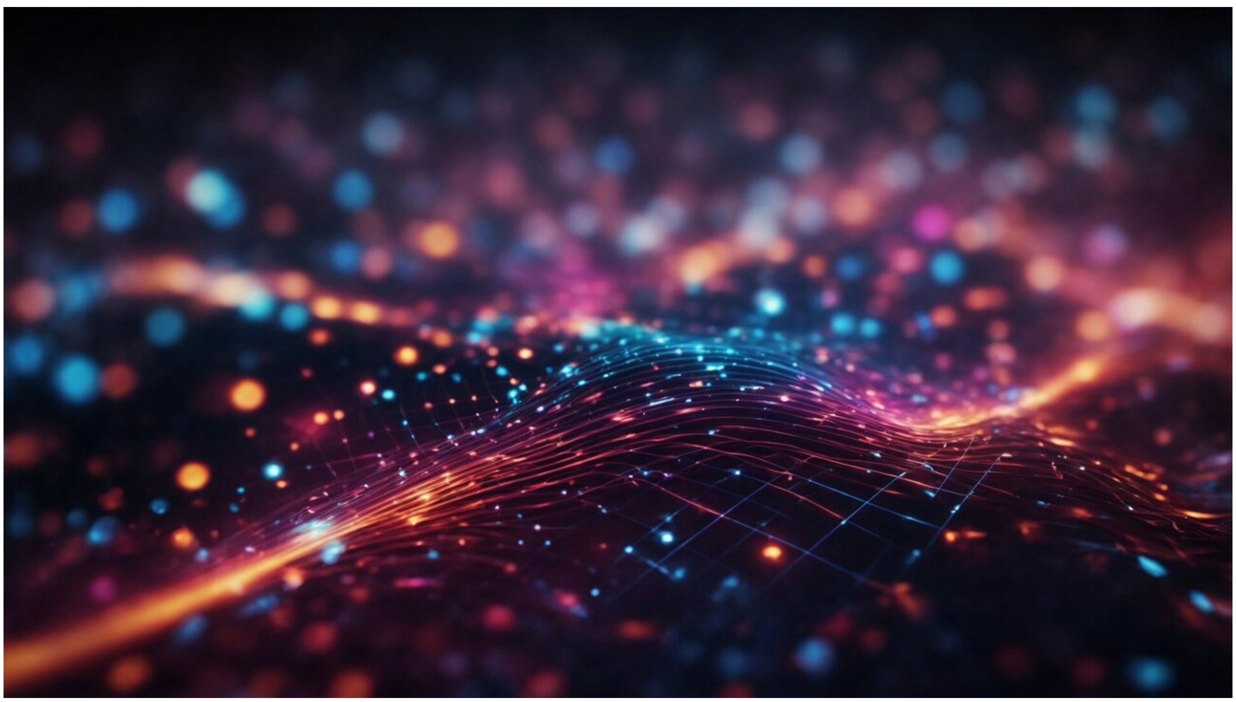

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In a continuous pursuit to understand the fundamental laws that govern the universe, researchers have ventured deep into the realms of string theory, loop quantum gravity, and quantum geometry. These advanced theoretical frameworks have revealed an especially compelling concept: the generalized uncertainty principle (GUP).

This principle fundamentally challenges traditional physics by proposing a minimal measurable length, which could profoundly alter our foundational understanding of space and time. It challenges the bedrock of classical mechanics and invites a reevaluation of quantum mechanics and general relativity.

The GUP has catalyzed an impressive range of research efforts, extending from the microscopic domain of atomic physics to the cosmic scales of astrophysics and cosmology. Investigations have explored phenomena such as gravitational bar detectors, condensed matter systems, and the dynamics of quantum optics.

Each study contributes to a broader understanding of the potential implications of the GUP, suggesting it could fundamentally transform our understanding of physics across various scales and systems.

Rethinking the Planck constant

Building upon these insights, our research, published in the *International Journal of Modern Physics D*, introduces a transformative concept: an "effective" Planck constant. This idea challenges the traditional view of the Planck constant as a static, immutable value, proposing instead that it might vary depending on specific experimental or environmental conditions, particularly the momentum or position of the system under observation.

This hypothesis emerges from the GUP, suggesting that the Planck constant is not merely a universal constant but dynamically interacts with the momentum and position of the physical systems being measured.

This new perspective encourages a rethinking of fundamental constants in physics, implying they could be dynamic properties interacting significantly with the physical attributes of systems, such as their mass, size, and quantum state.

A bridge between quantum mechanics and the cosmos

Central to our investigation is a simple yet profound formula: $m\ r\ c = \hbar'$

This formula demonstrates that by inputting the Planck mass and Planck length as the mass and radius, respectively, we derive what we term the "traditional" Planck constant, $\hbar$. This outcome highlights a significant and intrinsic connection between fundamental physical constants and the fabric of the universe.

When this formula is specifically applied to the electron, the results are particularly illuminating: $\hbar'$ equates to the fine structure constant multiplied by $\hbar$, aligning perfectly with established values from quantum mechanics. This precise alignment reinforces the robustness of our formula and its relevance to fundamental particle physics.

For particles like pions, kaons, and gauge bosons, the calculated $\hbar'$ remains comparable in magnitude to $\hbar$, demonstrating the universal applicability of our formula across different scales and particle types.

However, when applied to larger systems, such as chemical elements like helium and oxygen, $\hbar'$ significantly exceeds $\hbar$ by a few orders of magnitude (10 to 10^3), suggesting a scale-dependent variability of the effective Planck constant.

Most importantly, when the formula is applied to the entire universe, it yields a value for $\hbar'$ that offers a potential solution to the cosmological constant problem. This intriguing result suggests a novel approach to resolving one of the most challenging and persistent issues in theoretical physics. By bridging observed discrepancies in vacuum energy densities with empirical observations, the formula provides a reconciled understanding of cosmic phenomena.

Linking to the Bekenstein entropy bound

Furthermore, our research establishes a critical link between the variable Planck constant $\hbar'$ and the Bekenstein entropy bound—a fundamental principle that limits the amount of information that can be contained within a given physical system.

This connection not only supports the theoretical validity of the Bekenstein bound but also significantly enhances our understanding of the role of entropy and information at the quantum level across different scales and systems. This insight suggests a deeper, more nuanced understanding of the relationships between information, entropy, and fundamental constants in the universe.

Conclusion

The implications of our findings are both profound and potentially transformative. By establishing a bridge between quantum mechanics, thermodynamics, and cosmology, our research opens new avenues for a deeper understanding of the universe at its most fundamental level.

This work not only enriches our theoretical insights but also invites the scientific community to reconsider enduring mysteries in physics, such as the nature of dark matter and the cosmological constant problem.

We hope that this research will inspire further exploration and vibrant discussion within the scientific community. By examining the universe through this innovative theoretical lens, we advocate for a more holistic and comprehensive understanding of the fundamental principles that govern everything from the minutest particles to the vast expanses of space.

This journey into the depths of physical laws is far from complete, and we eagerly anticipate the new perspectives and discoveries that it will bring.

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More information: Ahmed Farag Ali et al, Theoretical and observational implications of Planck's constant as a running fine structure constant, *International Journal of Modern Physics D* (2024). DOI: 10.1142/S0218271824500366. On *arXiv*: DOI: 10.48550/arxiv.2210.06262

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