Revisiting the *Heisenberg Uncertainty Principle*: Why Photons Are Exempt from Quantum Uncertainty

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Abstract

In this article, we challenge the commonly accepted notion that the *Heisenberg Uncertainty Principle* (HUP) applies universally, including to photons (electromagnetic waves). While photons are fundamentally linked to *Quantum Mechanics* (**QM**) through the Planck-Einstein relation ($E = h\cdot\upsilon$), we argue that certain core aspects of their behavior (specifically their *speed*, *wavelength*, *frequency*, and *phase*) are fully deterministic and not subject to *uncertainty*. Through detailed mathematical exploration and comparison with traditional QM principles, we demonstrate that the HUP, although fundamental to particles with mass (fermions), does not meaningfully apply to massless bosons like photons. This insight paves the way for further exploration of deterministic principles for introducing a new *Quantum Gravity Dynamics* (QGD) conceptual alternative.

Introduction

The HUP is a cornerstone of QM, establishing inherent limits on the precision with which certain pairs of physical properties (such as position and momentum or energy and time) can be known. While this principle is crucial to understanding the behavior of particles with mass, such as electrons, we argue that it does not apply to massless particles like photons. Photons, which are described as *quanta* of electromagnetic radiation, exhibit wave-like behavior, which remains fully *deterministic* in terms of speed, frequency, wavelength, and phase.

This article revisits the application of the *Uncertainty Principle* to photons, examining both the theoretical and mathematical implications of treating photons as *deterministic* entities. Our conclusions show that the *Uncertainty Principle*, though critical to the description of *fermions*, does not extend to *bosons* in the same manner when applied at a quantum level. We argue that this realization is key to advancing the theoretical framework of *Quantum Gravity Dynamics* (QGD).

Section 1: The Nature of Photons and Quantum Mechanics

Photons are massless particles, with their energy determined by Planck's constant (h) and their frequency (f), as described by the Planck-Einstein relation:

$$E= h\cdot\upsilon= h\cdot c/\lambda \qquad [\ E= h\cdot \upsilon = h\cdot\frac{c}{\lambda}]$$

where **c** is the speed of light and **λ** is the wavelength. Additionally, the De Broglie relation connects the photon's momentum (p) to its wavelength (through $E=p\cdot c$):

$$p= h/\lambda. \qquad [\ p = \frac{h}{\lambda}\ ].$$

Photons travel at the constant speed **c** in a vacuum, a fundamental property of the electromagnetic wave, which is entirely *deterministic*. Unlike fermions, whose position and momentum are subject to the HUP, photons exhibit no *uncertainty* in their fundamental characteristics, such as *speed*, *frequency*, *wavelength* and *phase*.

Section 2: Application of the *Heisenberg Uncertainty Principle* (HUP) to Photons

The *Heisenberg Uncertainty Principle* is traditionally expressed as:

$\Delta x \cdot \Delta p \geq \hbar/2$ [\Delta x \cdot \Delta p ≥ \frac{\hbar}{2}]

where $\hbar$ is the reduced Planck's constant. For photons, we substitute the momentum expression from De Broglie's relation into the uncertainty principle:

$\Delta x \cdot \Delta(h/\lambda) \geq \hbar/2$ [\Delta x \cdot \Delta \left(\frac{h}{\lambda}\right) ≥ \frac{\hbar}{2},

which simplifies to:

$\Delta x/\Delta\lambda \geq 1/4\pi$ [\Delta x \cdot \Delta \lambda ≥ \frac{1}{4\pi}]

Given that **λ** is *deterministic* for *photons*, this result suggests that the *uncertainty principle* introduces no *quantum mechanical uncertainty* for *photons*. This relation, derived from the *uncertainty principle*, holds no physical meaning for massless particles like *photons*.

Similarly, the time-energy uncertainty relation:

$\Delta E \cdot \Delta t \geq \hbar/2$ [\Delta E \cdot \Delta t ≥ \frac{\hbar}{2}]

can be reformulated using the Planck-Einstein relation $E = h \cdot \upsilon$:

$\Delta(h \cdot \upsilon) \cdot \Delta t \geq \hbar/2$ [\Delta (h·\nu) \cdot \Delta t ≥ \frac{ℏ}{2}

This simplifies to:

$\Delta t/\Delta\lambda \geq 1/4\pi c$ [\frac{\Delta t}{\Delta \lambda} ≥ \frac{1}{4πc}]

again demonstrating no significant *quantum uncertainty* for *photons* ($\Delta x = c \cdot \Delta t$) , as the *uncertainty* in wavelength and time carries no inherent *quantum* limitation.

Section 3: Determinism in Photons and Electromagnetic Waves

While the HUP imposes *probabilistic* constraints on the behavior of *fermions*, *photons* follows *deterministic* principles as described by Maxwell's equations and Quantum Electrodynamics (QED). In electromagnetic waves, properties such as *speed, amplitude, frequency, and phase* are fixed and do not exhibit no quantum *uncertainty*:

- **Speed (c)**: The speed of light in a vacuum is constant and precisely defined.
- **Frequency (f) and Wavelength (λ)**: Both are fixed for a photon and exhibit no *quantum uncertainty*.
- **Phase (ϕ)**: The phase of electromagnetic waves is also deterministic and unaffected by *any quantum uncertainty*.

These *deterministic* aspects of electromagnetic waves contrast sharply with the probabilistic nature of *fermions* in QM. For *photons*, *quantum uncertainty* plays does not govern their core properties which challenges the universal application of the *Heisenberg Uncertainty Principle*.

Section 4: Implications of Feynman's *Quantum Electrodynamics Dynamics* (QED)

The deterministic nature of electromagnetic waves, as described by Maxwell's equations, provides the foundation for Feynman's *Quantum Electrodynamics*, which extends the *quantization* of the electromagnetic field. While QED introduces *probabilistic* interactions (such as photon absorption and emission), the behavior of *photons* themselves remains *deterministic*.

- Maxwell's Equations provide a *deterministic* description of electromagnetic wave propagation. QED adds a *probabilistic* layer to interactions with matter, but the photons themselves maintain deterministic properties. This raises important distinctions between wave propagation (*deterministic*) and particle interactions (*probabilistic*).
- Relation to Quantum Mechanics: The *deterministic* behavior of photons shows that not all *quantum* phenomena exhibit *uncertainty* in the same way. For photons, wave propagation is well-defined, whereas the *probabilistic* nature arises only in their interactions with matter.

This last point highlights how *determinism* can transition into *quantization*, suggesting potential applications for the development of *Quantum Gravity Dynamics* (QGD).

Section 5: Implications for *Quantum Gravity Dynamics* (QGD)

The deterministic nature of electromagnetic waves offers insight into developing a new framework for *Quantum Gravity Dynamics* (QGD). While particle with mass (*fermions*) are subject to *quantum uncertainties*, bosons such as photons follow deterministic principles. This dichotomy suggests that gravity, as a force acting on both massless and massive particles, may have both *deterministic* and *probabilistic* aspects.

The deterministic behavior of photons provides a model for understanding gravitational interactions that bypasses the need for a probabilistic description. *Quantum Gravity Dynamics* may leverage this determinism to formulate a coherent *quantum* theory of *gravity* that incorporates both the wave-like nature of massless particles and the particle-like nature of massive fermions.

Conclusion

This article challenges the conventional view that the *Heisenberg Uncertainty Principle* applies universally. For photons, the principle introduces no *uncertainty* in *speed*, *wavelength*, *frequency*, or *phase*. *Photons*, governed by Maxwell’s equations exhibit fully deterministic behavior although QED introduces probabilistic interactions in photon-matter coupling. These findings open the door to further exploration of *Quantum Gravity Dynamics*, where deterministic and probabilistic descriptions may coexist, offering a new path to understanding *gravity* at the *quantum* domain.

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