

Intrinsic Compton Waves and a Determinacy Principle for Light-Speed Wave Properties of Elementary Particles

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Abstract

This paper proposes a theoretical hypothesis that elementary particles possess an intrinsic internal wave identified as the Compton wave, which propagates at the speed of light, distinct from the de Broglie matter wave associated with subluminal particle motion. Starting from the definition of the reduced Compton wavelength $\bar{\lambda} = \hbar/(mc)$, we rearrange the relation to obtain $mc \cdot \bar{\lambda} = \hbar$, which bears a formal resemblance to the Heisenberg uncertainty principle but describes an exact equality rather than a lower bound. We interpret mc as the intrinsic momentum of the particle, analogous to the intrinsic rest energy $E = mc^2$. This exact equality is postulated to represent a *determinacy principle* governing the intrinsic wave nature of particles at light speed, in contrast to the uncertainty principle that characterizes subluminal particle motion and observer-dependent measurement effects. We further propose an experimental test analogous to Bell inequality tests, with the critical distinction that only wave properties of entangled particles are measured throughout the experiment, without interrogating particle-like attributes. The hypothesis predicts that wave characteristics will remain fully predictable with unit probability, independent of intermediate transformations, in contrast to the probabilistic outcomes of particle-property measurements.

Keywords

Compton Wavelength, Intrinsic Momentum, Determinacy Principle, Wave-Particle Duality, Bell Test, Quantum Foundations

1. Introduction

Wave-particle duality stands as a foundational principle of quantum mechanics,

formalized through two distinct wavelength scales: the de Broglie wavelength $\lambda_{\text{dB}} = h/p$ associated with the translational motion of massive particles, and the Compton wavelength $\lambda_{\text{Com}} = h/(mc)$ as a fundamental length scale tied to particle rest mass [1]. The de Broglie relation underpins the wave behavior of moving particles and is directly linked to the Heisenberg uncertainty principle $\Delta x \Delta p \geq \hbar/2$, which establishes an irreducible lower bound on the joint precision of position and momentum measurements.

The Compton wavelength, by contrast, has historically been interpreted primarily as a characteristic scale for quantum electrodynamic interactions such as Compton scattering and as a limit on position localization for massive particles. However, the reduced Compton wavelength $\bar{\lambda}_{\text{Com}}$ admits a deeper formal reading: rearrangement yields the exact equality $mc \cdot \bar{\lambda}_{\text{Com}} = \hbar$, which structurally mirrors the uncertainty product but holds as an identity rather than an inequality.

This work advances the hypothesis that this equality corresponds to a physical *determinacy principle* governing an intrinsic Compton wave that propagates at the speed of light within the particle. On this view, the uncertainty principle applies exclusively to the subluminal, particle-like aspect of quantum objects and to observer-mediated measurements, whereas the determinacy principle describes the light-speed, wave-like aspect as an observer-independent intrinsic property. We outline a Bell-type experimental protocol to test this proposition by measuring only wave observables of entangled systems, and we predict deterministic, unit-probability outcomes for such measurements.

2. Theoretical Formulation: Reduced Compton Wavelength and Intrinsic Momentum

We begin with the standard definition of the reduced Compton wavelength of a particle of rest mass m :

$$\bar{\lambda} = \frac{\hbar}{mc}, \quad (1)$$

where $\hbar = h/(2\pi)$ is the reduced Planck constant and c is the speed of light in vacuum. Multiplying both sides of Equation (1) by mc yields:

$$mc \cdot \bar{\lambda} = \hbar. \quad (2)$$

Equation (2) is mathematically trivial as an algebraic rearrangement, but we assign it nontrivial physical meaning. The quantity mc is interpreted as the intrinsic momentum of the particle, in direct analogy to the intrinsic rest energy $E = mc^2$. Just as rest energy is the energy content of a particle at rest, independent of its translational motion, intrinsic momentum mc is the momentum associated with the particle's internal light-speed wave dynamics, also independent of external translational velocity.

The product of this intrinsic momentum and the reduced Compton wavelength equals $\hbar$ exactly. This stands in marked contrast to the Heisenberg position-momentum uncertainty relation:

$$\Delta x \Delta p \geq \frac{\hbar}{2}, \quad (3)$$

which specifies a minimum uncertainty product for measured values of position and translational momentum. Equation (2), by contrast, is an exact equality relating two intrinsic, observer-independent properties of the particle.

3. The Determinacy Principle for Light-Speed Intrinsic Waves

We formalize the central postulate as follows.

Determinacy Principle: For the intrinsic Compton wave of an elementary particle, which propagates at the speed of light c , the product of the intrinsic momentum mc and the characteristic wavelength $\bar{\lambda}$ is exactly equal to $\hbar$. This relation holds deterministically and independently of any measurement interaction.

Physically, we interpret the principle as a demarcation between two regimes of quantum behavior.

1) Subluminal regime ($v < c$): When a particle is described in terms of its translational motion through space, it exhibits particle-like properties governed by the de Broglie relation and the Heisenberg uncertainty principle. Measurement back-action and wavefunction collapse introduce fundamental indeterminacy, reflected in the inequality form of Equation (3).

2) Luminal regime ($v = c$): The internal wave structure of the particle propagates at the speed of light and obeys the exact equality of Equation (2). This wave aspect is not subject to observer-induced uncertainty because it represents an intrinsic, dynamically stable configuration rather than a measurable translational degree of freedom.

This interpretation is consistent with the observation that the Compton wavelength is velocity-independent and depends only on rest mass, whereas the de Broglie wavelength scales inversely with particle momentum. The de Broglie wave can thus be understood as a Doppler-shifted manifestation of the underlying intrinsic Compton wave when the particle is in motion relative to an observer.

4. Proposed Experimental Test: Bell-Type Protocol for Wave-Only Observables

To empirically distinguish the determinacy principle from standard quantum mechanical predictions, we propose an experimental scheme modeled on Bell inequality tests [2]-[4], with a crucial modification: at no stage are particle-like properties (such as discrete detection events, position, or spin projection as a particle observable) registered. Instead, only wave-like properties, like interference patterns, phase coherence, and wavefront correlations, are measured throughout the apparatus.

4.1. Experimental Design

Consider a source producing pairs of entangled photons or massive particles in a

state where wave properties (e.g., orbital angular momentum modes or spatial wavefunction phases) are correlated. The protocol proceeds as follows.

- 1) Entangled particle pairs are emitted and directed to two spatially separated measurement stations.
- 2) Each station is configured to perform only wave-interference measurements, such as Mach-Zehnder interferometry or double-slit diffraction, without which-path detectors that would reveal particle-like trajectories.
- 3) Measurement bases (interferometer path-length settings) are randomly and independently adjusted at each station, as in standard Bell tests.
- 4) Correlations between the interference patterns observed at the two stations are recorded.

4.2. Theoretical Prediction

Standard quantum mechanics predicts that wave interference visibility and entanglement correlations follow probabilistic distributions that violate Bell inequalities when appropriate observables are chosen. Under the present hypothesis, however, if the measurement apparatus strictly probes only the wave nature of the system, never collapsing the wavefunction via particle-detection events, the correlations will exhibit deterministic behavior:

- The wave phase and amplitude relations between entangled pairs will be perfectly predictable given the initial state and the measurement settings.
- The observed correlation function will correspond to unit probability for the expected wave pattern, with no stochastic collapse event introducing probabilistic outcomes.

In other words, where standard Bell tests reveal probabilistic violation of local realism through particle-detection statistics, a wave-only Bell-type test is predicted to reveal deterministic wave correlations consistent with the determinacy principle.

5. Discussion

The proposed framework recasts wave-particle duality not as a single entity exhibiting mutually exclusive behaviors depending on measurement context, but as two ontologically distinct aspects: an internal light-speed Compton wave obeying exact determinacy, and a subluminal particle-like manifestation obeying quantum uncertainty. The measurement problem, on this view, arises from the interaction between the observer's apparatus (which operates in the subluminal particle regime) and the intrinsic luminal wave structure.

This interpretation aligns with earlier work noting that the Dirac equation implicitly contains Compton-frequency oscillation (*zitterbewegung*) as an internal dynamical feature, and with proposals that the Compton wavelength represents a more fundamental matter wavelength than the de Broglie wavelength [5]. It also resonates with models that describe fermions as localized light-speed circulatory motions characterized by the reduced Compton radius [6].

Several open questions remain. First, the precise ontological status of the intrinsic Compton wave, whether it is a physical wave in spacetime or a formal construct, requires further elaboration. Second, the mechanism by which subluminal particle behavior emerges from luminal internal dynamics must be specified in greater detail, ideally through a dynamical model connecting internal wave circulation to external translational motion. Third, the experimental proposal must be refined to specify precisely which observables count as “wave-only” and to quantify the predicted deviation from standard quantum predictions.

6. Conclusion

We have advanced the hypothesis that elementary particles possess an intrinsic Compton wave propagating at the speed of light, governed by an exact determinacy relation $mc \cdot \bar{\lambda} = h$. This relation is interpreted as a determinacy principle complementary to the Heisenberg uncertainty principle: the latter describes indeterminacy in subluminal particle motion and measurement, while the former describes exactness in the intrinsic luminal wave nature of the particle. A Bell-type experimental test using exclusively wave-property measurements has been proposed, with the prediction that wave correlations will be fully deterministic rather than probabilistic. If confirmed experimentally, this framework would extend our understanding of wave-particle duality and suggest that quantum indeterminacy is a feature of the particle-aspect and measurement interaction, not a fundamental property of the underlying wave reality.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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