On a Lorentz-Invariant Model of Time Irreversibility and Superweak Quantum Measurements for Its Verification

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Abstract

This paper explores the development of Penrose's hypothesis regarding the time asymmetry of the most general physical laws. A description of quantum phenomena is proposed using Lorentz-invariant differential equations with derivatives of infinite order. It is shown that such equations lead to an explicit time irreversibility—even at the level of quantum processes. To test this model, a modified version of the double-slit experiment is proposed. If the hypothesis is correct, the experimental results will contradict the predictions of standard quantum mechanics.

1. Introduction

Fundamental physical laws, such as those of relativity and quantum theory, are symmetric under time reversal. However, observational evidence points to the existence of a cosmological arrow of time. This suggests that the fundamental equations of physics may in fact be asymmetric with respect to time.

In 1978, Roger Penrose proposed that the most fundamental physical laws are inherently time-asymmetric[1-2], and that the time-symmetric equations currently accepted in physics are merely approximations of deeper, asymmetric principles. If this hypothesis is correct, it could provide a meaningful explanation for the origin of time's arrow.

The primary aim of this work is to develop Penrose's hypothesis into a mathematical model that yields concrete, testable predictions[4].

2. Lorentz Invariance and Nonlocality

Any fundamental equations describing physical phenomena must respect Lorentz invariance. Lorentz invariance implies time isotropy—but only when the differential equations contain derivatives of finite order. For Lorentz-invariant differential equations of infinite order, this implication fails: such equations become nonlocal in both space and time.

Consider, for example, an equation of the form:

$$\sum_{i=0}^{i=\infty} f_i(\Box^i u, u) = 0 \tag{1}$$

Where $\Box$ is the d'Alembert operator, u is a scalar field.

We analyze an inductive solution method by increasing the order of differential operators step by step. $k = 1$, $u_{n+k} = u(t + k\tau)$.

$$u_{tt} = 0 \approx \frac{u_{n+1} - 2u_n + u_{n-1}}{\tau^2}; u_{n+1} \approx \tau^2(2u_{n+1} - u_n) \tag{2}$$

$k = 2$

$$u_{tttt} = 0; u_{n+2} \approx \tau^4(4u_{n+1} - 6u_n + 4u_{n-1} - u_{n-2}) \tag{3}$$

For instance, with $K = 1$, and letting the current moment be $u_{(n+k)}$ we examine the behavior as $k \to \infty$, simultaneously letting $\tau = 1/k \to 0$. This leads to nonlocality.

Due to this nonlocality, the solution at a particular point in space and time depends on a finite interval of past time and a finite spatial neighborhood. As a result, explicit time asymmetry emerges: time reversal would require symmetric behavior of the field in both forward and backward time intervals.

3. Connection to Quantum Foundations

Such infinite-order equations may also shed light on foundational issues in quantum mechanics. According to Lee Smolin, one possible direction is to construct a realist theory in which the concepts of "measurement" and "observation" play no privileged role[3-4]. In conventional quantum mechanics, measurement is treated as an absolute process, causing the instantaneous collapse of the wavefunction. This collapse is separated from the ordinary interaction of a particle with its environment.

By contrast, in the framework of equation (1), the particle is treated as a soliton-like solution interacting nonlocally with its environment within a finite spacetime region. The process of measurement is naturally embedded into this nonlocal interaction and does not play a special role.

4. Experimental Proposal

To test this hypothesis, the following experiment is proposed. In a Young's double-slit setup, only one slit (e.g., the first) is opened during the time interval when particles are most likely to pass through both slits.

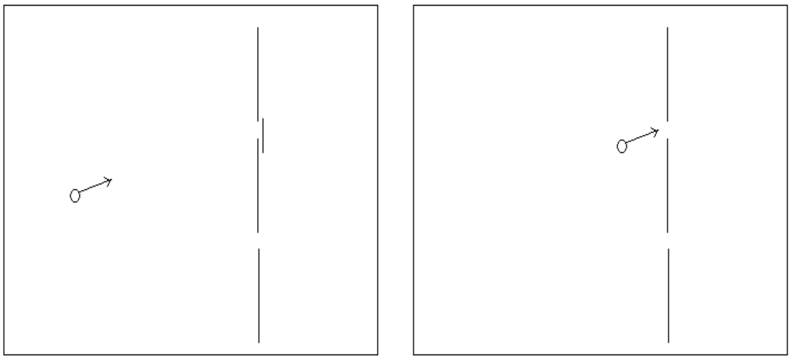

Figure 1:

(a) If standard quantum mechanics holds, this modification should not disturb the interference pattern on the screen.

(b) If, however, the nonlocal model with infinite-order derivatives is valid, then—within the nonlocality radius—the particle will effectively "know" that one slit is closed for most of the time. This should significantly alter the interference pattern.

One argument against the absolutization of the measurement process comes from so-called *weak measurements*, which show that partial erasure of a particle's directional information is possible. For this reason, the proposed experiment may be considered a *superweak measurement*—since, according to quantum mechanics, it should not affect the interference pattern at all.

Although the idea behind such an experiment may seem exotic, and its result may appear predetermined in favor of quantum mechanics, this cannot be definitively asserted prior to conducting it.

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