On a modified double-slit experiment to test the hypothesis of interference as a result of space-time nonlocality described by equations with infinite-order derivatives

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Abstract

A modified version of Young's experiment is proposed to test the hypothesis that double-slit interference arises from space-time nonlocality, described by Lorentz-invariant equations with derivatives of infinite order. If this hypothesis is correct, the experimental results would differ from the predictions of quantum mechanics.

Keywords:non-locality, nonlinear differential equations, soliton.

1   Introduction

The double-slit experiment, originally conducted by Thomas Young with light, is one of the most fundamental experiments in quantum mechanics. It demonstrates that light, as well as other particles such as electrons, can exhibit both wave-like and particle-like behavior.

In the experiment, light or a stream of particles is directed at a screen with two slits. An interference pattern of alternating bands of maxima and minima forms on the screen behind the slits. If photons were only particles, two bright spots would appear behind the slits. However, the observed interference pattern suggests that photons pass through both slits simultaneously, interacting with themselves as waves do.

The uniqueness of the experiment with single photons lies in the fact that even when photons are emitted one by one, an interference pattern still gradually forms on the screen. This result is fundamental to the understanding of quantum mechanics and its probabilistic nature, where particles do not have a definite trajectory until measured. The single-photon double-slit experiment vividly illustrates that the quantum world is different from the classical one, where particles have definite trajectories and cannot pass through multiple places at once.

Another manifestation of quantum effects is the violation of locality, in which the properties of two or more particles remain correlated regardless of the distance between them. This means that measuring one particle's property can instantly affect the other's, even at large separations. The violation of Bell's inequalities, observed experimentally, is one of the main pieces of evidence for the existence of quantum nonlocality [1-3].

2   On a modified double-slit experiment

Let us consider the behavior of a particle in the double-slit experiment before it hits the screen. Locally, the particle only interacts with the boundaries of the slits. In the absence of external fields, the particle must possess information about its flight direction to produce an interference pattern-that is, information about the experimental geometry, previous particles, etc. A logical possibility for how the particle acquires this information at a distance is nonlocality,

described by equations with infinite-order derivatives. Nonlocality is usually understood as spatial nonlocality, but any Lorentz-invariant nonlocal theory must also be nonlocal in time.

Nonlocality can be described by differential equations with infinite-order derivatives, for example, involving an infinite number of terms like

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

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

With a specific power of the infinite order, such nonlocality becomes finite in time and space, with a certain finite radius of nonlocality. The manifestations of this kind of nonlocality should differ from those described by quantum mechanics. If particles involved in double-slit interference are considered as solitons, then the behavior of one particle can be influenced by the past behavior of another particle within the radius of nonlocality. The selectivity of this influence might be explained by the identical frequencies of soliton oscillations or some kind of resonance. It is known that to form an interference pattern [4-6], a fairly large number of particles-on the order of $10^3 - 10^4$ -is required.

However, assuming a finite nonlocality radius, if such experiments are divided into many temporally separated runs, then when comparing the results, the interference pattern should be disrupted according to this model. These experiments must be separated in time by an interval exceeding the assumed radius of nonlocality. For example, if identical experiments are conducted with 1-2 particles per time interval and a significant time delay (initially, say, $t > 10^3 s$) between them, then this finite nonlocality model predicts a breakdown of probabilistic interference when their results are combined.

Additionally, during the delays between particle detections, the experiment may continue with the screen and one slit closed. If one of the slits is opened only during the expected moment of particle passage, this deprives the particle of some information about the current experimental geometry. If interference depends on the experiment's history and geometry, this should also disrupt the interference pattern in such a model.

If quantum mechanics holds, the interference pattern should remain intact. Although the idea of such an experiment is quite exotic and its results seem predetermined in favor of quantum-mechanical description, this cannot be definitively asserted without actually performing it.

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