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Tachyons and Quantum Statistics

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A number of years ago, Bohm postulated the existence of a quantum potential in order to create a completely causal description of nonrelativistic quantum mechanics. It is shown that this quantum potential must be a tachyon field. An experimental test of the identification of tachyons with Bohm's quantum potential is described. It is shown that though in the above experiment spacelike intervals are investigated, the information arrives after timelike intervals. The experiment thus provides an example where tachyons can affect a measured quantity though they cannot be used to violate causality.

I. INTRODUCTION

Considerable interest has been given recently to the possible existence of tachyons.[1-3] The primary theoretical problem associated with tachyons is that of causality violation. For example Pirani[4] showed that causality violation can take place through the transmission of classical tachyons between three or more observers in such a way that each observer receives and transmits only tachyons whose energy he measures to be positive. Benford, Book, and Newcomb[5] used Tolman's[6] argument to show that the existence of tachyons would give rise to causal contradictions. Rolnick[7] showed that the reinterpretation of negative-energy particles traveling backward in time as positive-energy particles traveling forward in time fails to resolve the causal anomaly of tachyons. It was noted by Bers, Fox, Kuper, and Lipson[8] that the Green's function for an imaginary-mass Klein-Gordon wave exhibits an absolute instability. Gluck[9] demonstrated that a causal Lorentz-invariant tachyon propagator is not expressible as a contracted Wightman function. It was shown, however, by Fox, Kuper, and Lipson[10,11] that a faster-than-light group velocity does not imply causality violation.

Concerning the possible existence of charged tachyons, Cawley[12] showed that the classical self-energy problem for charged tachyons is very serious. Other reasons against the existence of charged tachyons were given by Baldo, Fonte, and Recami.[13]

Efforts to detect tachyons have so far yielded negative results.[14-19] Experimenters must grope very much in the dark, as nothing is known about the interactions in which tachyons are likely to participate or where they may be found. To help remedy this situation, the possible identification of Bohm's quantum potential with the tachyon field is explored in this paper. The identification is made in Sec. II, and in Sec. III an experimental test is described. Finally, in Sec. IV, the problem of causality violation is discussed.

II. THE TACHYON FIELD AS A QUANTUM FIELD

A number of years ago, Bohm[20] postulated the existence of a quantum potential in order to create a completely causal description of nonrelativistic quantum mechanics. In an n-particle system, the quantum potential depends on the coordinates of all n particles. The quantum potential postulated by Bohm acts between the n particles, assuring that a completely deterministic behavior of the n particles produces the statistics of quantum mechanics. The quantum potential is exactly determined by the n-particle wave function which satisfies Schrödinger's equation.

What is the velocity of propagation that U would have in a relativistic extension of Bohm's causal description? In Bohm's nonrelativistic description, the quantum potential U, similar to all nonrelativistic potentials, acts instantaneously. If in a nonrelativistic theory a two-particle potential was proportional to $1/|\vec{X}_1 - \vec{X}_2|$, we could infer that the field propagates, in a relativistic extension, with the speed of light, as do the electromagnetic and gravitational fields. On the other hand, if the potential was proportional to $\exp(-m|\vec{X}_1 - \vec{X}_2|)/|\vec{X}_1 - \vec{X}_2|$, we could infer that the field propagates with less than the speed of light, in a relativistic extension, similar to the boson and baryon fields. The nonrelativistic form of U, however, does not help to determine its velocity of propagation, since it can be quite general.

The velocity of propagation of U, however, can be determined from the following. In the Einstein, Podolsky, and Rosen[21] experiment or its Bohm variant,[22] a measurement of particle 1 affects the measurement of particle 2 even though particles 1 and 2 are quite separated. This eliminates the possibility that U is short-ranged and subluminal such as the boson and baryon fields.

To determine whether U is luminal or superluminal we use the following. Relativistic quantum mechanics provides a satisfactory description of relativistic particles. Two relativistic particles can be traveling in opposite directions infinitesimally close to, or at, the velocity of light. If U were luminal, it would then take an infinite time for U to cover the distance from particle 2 to particle 1.

We find then that *U must be superluminal and is a tachyon field.*

We are interested in characterizing the field such that it is subject to experimental investigation. Let Δt_c be the time it takes light to travel between two points, such as two detectors, and ΔT be the time resolution of the measuring system, with $\Delta T < \Delta t_c$. If ΔT is a time interval between the two points, then $(\Delta t_c)^2 - (\Delta T)^2$ would be the invariant spacelike interval (velocity of light is unity). The largest possible spacelike interval is $(\Delta t_c)^2$ (with $\Delta T = 0$). A convenient parameter for characterizing the experimental apparatus investigating the spacelike intervals is the fraction of the spacelike intervals that the apparatus is sensitive to, or

$$\delta \equiv 1 - \frac{(\Delta t_c)^2 - (\Delta T)^2}{(\Delta t_c)^2} = \left(\frac{\Delta T}{\Delta t_c}\right)^2 . \tag{1}$$

Of course, δ is a Lorentz-invariant quantity.

We assume that tachyons of all velocities carry the information of quantum mechanics. It is of interest to see the way tachyons of different velocities contribute to an experimentally measured quantity. Let v be the velocity of a particular tachyon in one Lorentz frame, and a second Lorentz frame moves with a velocity $1/v$ with respect to the first frame in the direction of the tachyon. The tachyon appears in the second Lorentz frame to have infinite velocity. If now, for example, δ in Eq. (1) is close to zero, then the experimental apparatus is insensitive to tachyons with less than infinite velocity. In a second Lorentz frame, however, the experimental apparatus becomes insensitive to the infinite-velocity tachyons of the first frame (since they now have finite velocity) but does become sensitive to tachyons that are of finite velocity in the first frame (since they now have infinite velocity).

For δ less than unity we expect deviations of an experimentally measured quantity from the prediction of quantum mechanics. We do not know, however, the dependence of the experimentally measured quantity on δ and the deviation may not become appreciable until δ approaches zero.

III. AN EXPERIMENTAL TEST

Low-energy proton-proton scattering has been suggested elsewhere[23] for testing Bell's[24] description of local hidden-variable theories. With a little modification, this experiment can be used to test the identification of the tachyon field with the quantum field (for greater detail see Ref. 23). A high-intensity low-energy (~1–4 MeV) proton beam is scattered from a proton-containing target; each of the two emitted protons (with a 90° angle between them) enters a polarization analyzer (suggested to contain helium gas). The incident beam is pulsed with a time width of less than a nanosecond (10^{-9} sec).

The low-energy proton-proton scattering takes place almost entirely through the singlet-S-wave channel with a total angular momentum of zero. The small P-wave contribution can be eliminated by performing the experiment at several scattering angles near 45°. Helium gas is suggested to be used in the analyzer since it has been shown[25, 26] that polarizations of 80–90% are obtained for scattering low-energy protons from helium at back angles.

Let ϕ be the angle between the polarization axis of the analyzer and the direction of polarization of a polarized beam incident to the analyzer for testing purposes. Let I_0 be the intensity of the incident beam and $I(\phi)$ the count rate of the analyzer at an angle ϕ. Then the polarization of the analyzer is defined as

$$P \equiv \frac{I(0°) - I(180°)}{I(0°) + I(180°)} , \tag{2}$$

while the transmission is defined as

$$T \equiv \frac{I(0°) + I(180°)}{2I_0} . \tag{3}$$

Now in our experiment let $R(1, 2)$ be the rate at which protons entering analyzer 1 are in coincidence with protons entering analyzer 2, and let $R(\theta)$ be the coincidence rate between analyzers 1 and 2, where θ is the relative angle between the polarization axes of the two analyzers. The experimental quantity that is suggested to be studied in the above experiment is

$$F \equiv \frac{|R(120°) - R(60°)|}{R(60°) - R(1, 2)T_1T_2(1 - P_1P_2)} , \tag{4}$$

where T_1, T_2 and P_1, P_2 are the transmission and polarization of analyzers 1 and 2, respectively. It is easily shown that the function F is independent of T and P, or,

$$F = \overline{F} \equiv \frac{|\overline{R}(120°) - \overline{R}(60°)|}{\overline{R}(60°)} , \tag{5}$$

where $\bar{R}$ is the coincidence rate for ideal analyzers ($P_1 = P_2 = 1$, $T_1 = T_2 = \frac{1}{2}$). In particular, evaluating $\bar{F}$ in (5) according to quantum mechanics, we obtain

$$\bar{F}_Q = 2. \tag{6}$$

In the above experiment, an over-all time resolution, ΔT, of a nanosecond, primarily determined by the analyzer detectors and the pulse width of the incident beam, is not difficult to attain. The analyzers are then separated by several meters to attain an appreciable δ in Eq. (1).

For a given δ, how much of a deviation in the experimentally measured F from Eq. (6) may be anticipated? If we assume that as δ approaches unity F is determined locally, then it can be shown[23, 24] that F becomes less than 1. Appreciable changes in F thus may be expected.

IV. CAUSALITY VIOLATION

If for δ small enough in the above experiment, F is observed to deviate statistically from Eq. (6), we might expect to be able to use the above experiment to violate causality. For example, the following may be envisaged. Observer 1 changes the polarization axis of analyzer 1 at a time t_1. Observer 2 at analyzer 2 at time t_2, moving at a small velocity away from observer 1, notices the change in the number of protons detected (which differs from the quantum-mechanics prediction) and immediately alters his polarization axis. Observer 1 then notices the induced change in the number of detected protons of analyzer 1 at time t_3. Since analyzers 1 and 2 are connected by spacelike intervals, we would expect that t_3 may be less than t_1 and causality is violated.

The fallacy in the above is the following. When observer 1 changes the polarization axis of analyzer 1 he does not change the number of protons detected by analyzer 2. The protons entering analyzer 2 are unpolarized before entering and remain unpolarized afterwards. What *does* change is the number of protons detected by analyzer 2 that are *in coincidence* with analyzer 1. This requires a signal traveling, say, at the speed of light from observer 1 to observer 2 to inform observer 2 when a proton is detected. The time to send a signal from observer 1 to observer 2 is then not $t_2 - t_1$ but Δt_c. Though $t_2 - t_1$ is a spacelike interval, Δt_c is not and causality cannot be violated.

It is to be noted that the experiment provides an example where tachyons can affect a measured quantity, though can not be used to violate causality. Other such examples in nature may exist.

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