CPT Invariance and Interpretation of Quantum Mechanics

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This paper is a sequel to various papers by the author devoted to the EPR correlation. The leading idea remains that the EPR correlation (either in its well-known form of nonseparability of future measurements, or in its less well-known time-reversed form of nonseparability of past preparations) displays the intrinsic time symmetry existing in almost all physical theories at the elementary level. But, as explicit Lorentz invariance has been an essential requirement in both the formalization and the conceptualization of my papers, the noninvariant concept of T symmetry has to yield in favor of the invariant concept of PT symmetry, or even (as C symmetry is not universally valid) to that of CPT invariance. A distinction is then drawn between "macro" special relativity, defined by invariance under the orthochronous Lorentz group and submission to the retarded causality concept, and "micro" special relativity, defined by invariance under the full Lorentz group and including CPT symmetry. The CPT theorem clearly implies that "micro special relativity" is relativity theory at the quantal level. It is thus of fundamental significance not only in the search of interaction Lagrangians, etc., but also in the basic interpretation of quantum mechanics, including the understanding of the EPR correlation. While the experimental existence of the EPR correlations is manifestly incompatible with macro relativity, it is fully consistent with micro relativity. Going from a retarded concept of causality to one that is CPT invariant has very radical consequences, which are briefly discussed.

1. INTRODUCTION

A preceding paper emphasized that intrinsic time symmetry—a property shared by classical theories of dynamics, wave propagation, probability, and information, and by the quantal theories of particles and (largely) of 1

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2 The following discussion will show that CPT invariance is the covariant (and very legitimate) heir of the classical T symmetry.
fields— is of critical importance in the fundamental problem of the interpretation of the quantum theory. It was stressed there that the wave collapse, that is, the stochastic event, or transition of quantum mechanics shares the time symmetry of all elementary phenomena. An example given was the formula\(^4\)

\[
\langle x | a \rangle = \langle x | x' \rangle \langle x' | a \rangle
\]  

(1)

solving the Cauchy problem\(^4\) for the Klein–Gordon or the spinning waves equations of Dirac, Petiau–Duffin–Kemmer, etc. In the relativistically covariant formalism of first quantization\(^5\) this formula yields the expansion of the wave function \(\langle x | a \rangle\) at any point-instant \(x\) in terms of the complete set of orthogonal Jordan–Pauli propagators \(\langle x | x' \rangle\) with apexes \(x'\) on an arbitrary spacelike surface \(\sigma\), the coefficients of the expansion being the values \(\langle x' | a \rangle\) of the wave function on \(\sigma\). Orthogonality of two Jordan–Pauli propagators with spacelike separation of their apexes \(x'\) and \(x''\) follows from the formula

\[
\langle x' | x'' \rangle = \langle x' | x \rangle \langle x | x'' \rangle
\]  

(2)

as the Jordan–Pauli propagator is zero outside the light cone.

In formulas (1) and (2) the operation \( \langle x | x \rangle \) is an invariant integral over a spacelike surface \(\sigma\), in the form of the flux of the (conservative) Gordon or Dirac-style 4-current.

Formula (1) shows that the Jordan–Pauli propagator is the eigenfunction in the covariant position measurement problem,\(^5\) formulated as, “Do we find at the pseudoinstant \(\sigma\) the particle crossing a given element of \(\sigma\)” (the corresponding probability density being the flux of the Gordon or Dirac-style current, respectively). The point is that the Jordan–Pauli propagator is nonzero inside both the future and the past, so that the stochastic event associated with the position measurement is a time-symmetric “collapse-and-anticollapse.”

\(^3\) State vector collapse is taken by some as a more rigorous wording. We express this concept by the shorter and more intuitive wording of wave collapse.

\(^4\) We are using Dirac’s notation together with his remark that an expansion \(\psi'(x) = \sum c_i \phi_i(x)\) can be written (summation sign omitted) \(\langle a | x \rangle = \langle a | I \rangle \langle I | x \rangle\), where \(\psi\) and the \(\phi_i\)'s are interpreted as transition amplitudes. See Refs. 2 and 3.

\(^5\) As, in the formalism of Ref. 5, the Jordan–Pauli propagator is the Fourier transform of the Fourier nucleus, the position operator associated with the Klein–Gordon equation is the four-vector \(x\) modulo that it ends on \(\sigma\) (that is, three degrees of freedom and not four; for example, the components of \(x\)). This statement does not contradict the more complicated expression of the Newton–Wigner position operator, where by definition only positive frequencies are accepted, because my formalism essentially requires both the positive and the negative frequencies on an equal footing.\(^6\)